Improved Mapping of Snow Water Equivalent over Quebec

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ABSTRACT

This extended abstract describes initial results from a project to develop 10-km resolution gridded maps of SWE over Québec from historical surface observations of snow depth and SWE. The project has assembled an historical snow course database for Quebec and surrounding regions containing ~145,000 observations covering the period 1936-2006. The SWE observations are interpolated to a 10 km grid using the method of kriging with external drift (KED) following Tapsoba et al. (2005) with topography and estimated SWE as external drift variables. The estimated SWE field is generated using precipitation from the CANGRD product (Milewska et al., 2005) and 6-hourly air temperatures from the NCEP reanalysis. The results of an initial evaluation showed the KED method provided spatially realistic SWE fields over Quebec with a number of improvements over the optimal-interpolation approach used in Brown et al. (2003). While the distribution of the available surface observations is quite variable in space and time there are sufficient observations to generate SWE maps for most of Quebec from about the mid-1960s for the 1st and 15th of the month from December to June.

Keywords: snow water equivalent, SWE, Quebec, kriging

INTRODUCTION

Snow accumulation over Quebec and adjacent Labrador is significant at a continental scale representing the second largest maxima after the western cordillera with annual maximum snow accumulations averaging 200-300 mm of water equivalent. This resource is of vital importance to the economy, ecology and society of Quebec. For example it is estimated that 1 mm of SWE in the headwaters of the Caniapiscau-La Grande hydro corridor is equivalent to $1M in hydro-electric power production (R. Roy, personal communication, 2006). However, relatively little has been published about snow cover variability and change in this region of North America due to spatial and temporal limitations in the available snow observing systems. Extensive in situ data are available from about the mid-1960s but the observations tend to be concentrated over southern Quebec. Passive microwave satellite data offer the potential for consistent spatial mapping of SWE from 1978 but research is still ongoing to develop reliable SWE algorithms that work for the deeper snow conditions and extensive forest cover that characterizes much of Quebec.

Brown et al. (2003) developed a gridded SWE product for North America from surface snow depth observations using an objective analysis methodology developed at the Canadian Meteorological Centre (Brasnett, 1999). However, this dataset is limited to a relatively short period (1979-1997) and the SWE values were derived using snow density estimated from a simple

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snowpack model. The main motivation for this project was to generate gridded SWE values over Quebec for a much longer period using the available SWE observations directly to provide a high quality dataset for investigating the spatial and temporal variability in SWE over Quebec and for use in evaluating climate and hydrological models.

DATA SETS

Historical Snow Course Observations

The main SWE data source was the historical snow course compilation for Canada prepared by the Meteorological Service of Canada in 2000 (MSC, 2000) supplemented with the Quebec snow course data maintained by the Quebec Ministère du Développement durable, de l'Environnement et des Parcs (MDDEP) which includes observations from Hydro-Quebec, Alcan, and the Churchill Falls Power Corporation. A total of 171,649 SWE observations were found in Quebec and adjacent provinces covering the period from 1908 to 2006 but the observing network is sparse prior to about 1960. These were checked for duplicates and internal consistency (snow density in the range 10-900 kg.m^{-3}) with only 7 records failing the density check which is a testament to both the observers and the collection agencies. A considerable number of duplicate records existed due to overlap of the various data sources. After these were removed the final dataset comprised 144,301 unique records mainly located in southern parts of the study region (Fig. 1). The snow course dataset is overwhelmingly dominated by bi-monthly observations made on-or-near the 1st and 15th of each month from December to June. The snow course data were supplemented with daily snow depth observations from climate and synoptic stations with SWE estimated using snow density interpolated from the snow course data.

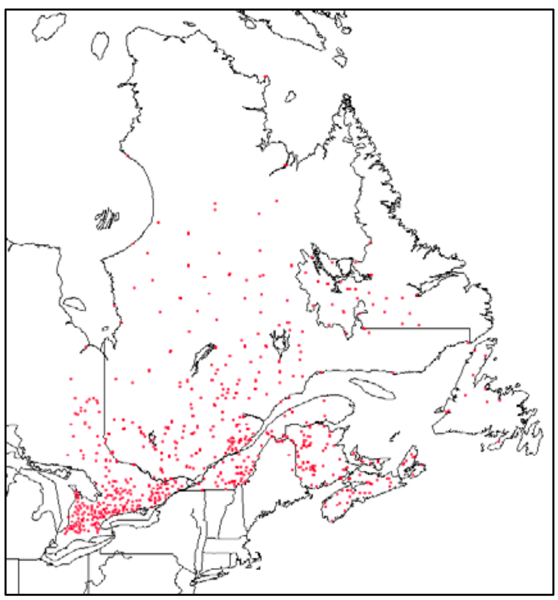

Figure 1. Location of snow course observations with complete observations of March 01 SWE during the decade of the 1970s.

Reconstructed SWE (NCEP+CANGRD)

A spatially and temporally complete reconstructed SWE field was used to provide additional information to the kriging process as an external drift variable. SWE was reconstructed using the simplified melt-index model of Brown et al. (2003) with 6-hourly 2m air temperatures from the NCEP reanalysis and daily precipitation from the 2007 update of the CANGRD (Milewska et al., 2005) product which provides gridded monthly total precipitation on a 50-km grid over Canada corrected for inhomogeneities and systematic errors (e.g. gauge undercatch) and adjusted for topographic and physiographic influences. The CANGRD product was found to provide superior results to SWE reconstructions using precipitation from NCEP or ERA-40. Daily precipitation totals were estimated by multiplying the CANGRD monthly total precipitation by the daily fraction of monthly precipitation from NCEP. Precipitation was multiplied by an empirically-derived adjustment factor (0.87) to correct for excess winter snow accumulation as the melt-index model did not take sublimation losses into account. The melt index values used in Brown et al. (2003) were found to melt snow too quickly in the spring period so these were also empirically adjusted to provide unbiased estimates of spring period SWE over the main SWE accumulation region of central Quebec.

The revised reconstruction exhibited good overall agreement with the SWE climatology of Brown et al. (2003) (Fig. 2). Correlation analysis of all pairs of observed and reconstructed SWE values with a separation distance of <10 km for March 01 yielded significant correlations over most of the study region where there were sufficient observations for the analysis (77% of correlations were > 0.6). The correlations exhibited a large degree of spatial variability which is likely related to a combination of factors including simplifications in the snow model (i.e. vegetation and topography not taken into consideration), the sparse precipitation observing network available to CANGRD, and to local factors influencing the SWE observations.

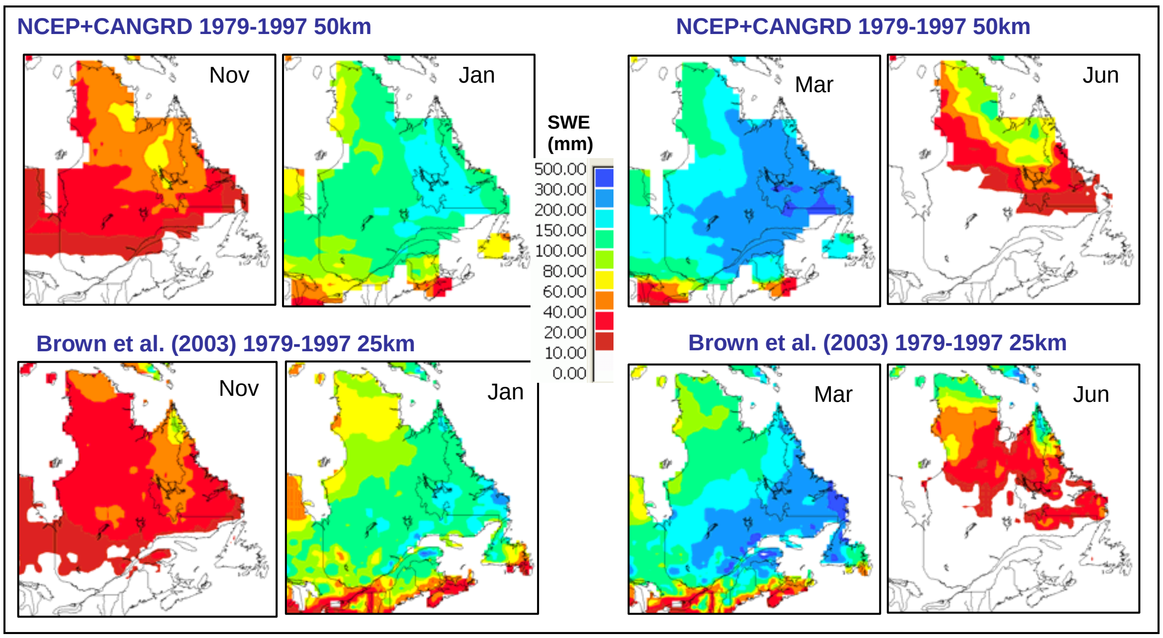

Figure 2. Comparison of the reconstructed SWE monthly climatologies (NCEP+CANGRD) with the Brown et al. (2003) dataset for the 1979-1997 period.

METHODOLOGY

Kriging with external drift (KED) is a well-documented and widely used geostatistical method for data interpolation (Hudson and Wackernagel, 1994; Wackernagel, 2003) and has been successfully applied to interpolate SWE over the Gatineau Rver Basin (Tapsoba et al., 2005). The essential problem of interpolating SWE with the KED method is how to combine point snow course observations and spatial information from a number of potential predictors in an optimal way to interpolate SWE at other locations. KED estimation of SWE at location (x) is made from

$$SWE(x) = a_0 + a_1S(x_1) + a_2S(x_2) \ldots + R(x)$$

where S(x) is the deterministic component based on the linear regression of SWE observations with the external drift predictor variables and the R(x) is a random residual component defined from the modelled variogram of the residuals from the regressions. Two drift predictors were used in this initial evaluation of the method; surface elevation above sea level and the estimated SWE from NCEP+CANGRD. The process requires developing a mean variogram for each SWE map date from the 1st and 15th of each month from December to June. This is done by computing the variogram for each year from 1970 to 2005 then averaging the results as shown in Figure 3. Good consistency was observed in the variograms between years and between map dates.

Cross-validation was carried out for March 15 (the approximate date of maximum annual SWE for most of Quebec) for a random selection of 25% of the observations (~130 obs/yr) over the 1970-2005 period. To evaluate the value added by each of the external drift variables, the root-mean-squared-error (rmse) was computed for interpolation results with topography and estimated SWE as single external drift variables, and for both variables combined. A simple interpolation procedure (Thiessen polygon method) was also included in the validation as a reference. The results are summarized in Table 1 below and show that each drift variable separately had a lower rmse than Thiessen. The combined variables offered only a small improvement in rmse at the evaluation locations but did have a noticeable impact on reducing interpolation errors over data sparse regions.

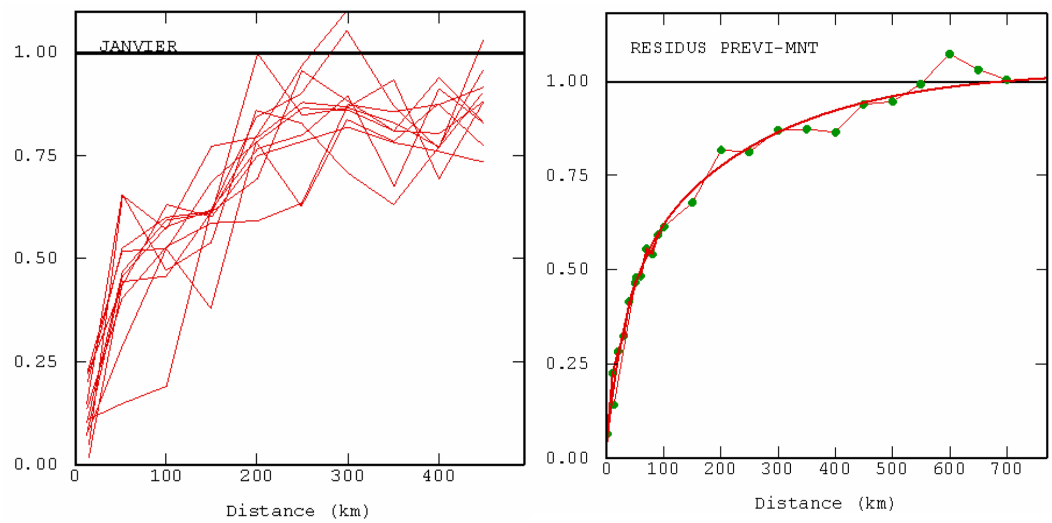

Figure 3. Construction of the mean normalized variogram (right) from annual variograms for January 01 SWE from 1970 to 2005 (left).

Table 1. Results of cross-validation for March 15 SWE, 1970-2005 (~130 stations).

	Topog	est SWE	Topog + est SWE	Thiessen
rmse (mm)	33.6	34.26	32.41	44.5

RESULTS

An example of KED interpolate SWE using topography and estimated SWE as external drift variables is shown in Figure 4 for March 15, 1979 along with the corresponding SWE field from Brown et al. (2003). From this preliminary result it appears the KED method provides improved detail in coastal regions and areas with complex topography, and does not “smear” individual station anomalies to the same extent as Brown et al. (2003). A full series of SWE maps covering the period 1970-2005 will be generated over the summer of 2007 and will be published in the fall-winter of 2007. The KED methodology described here has also been found to have potential for real-time operational monitoring of SWE anomalies.

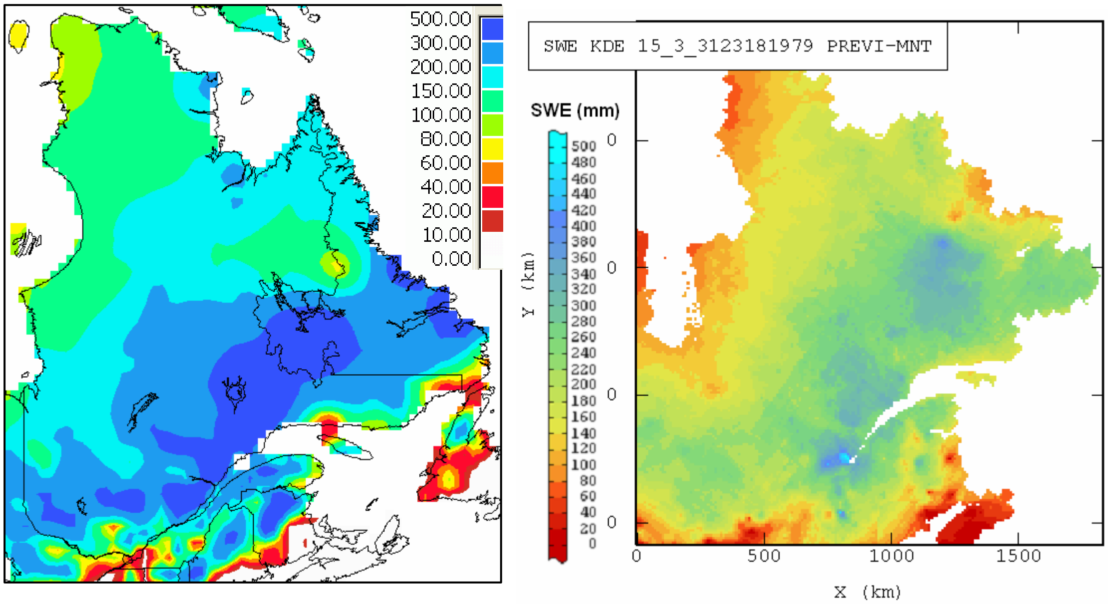

Figure 4. Comparison of SWE maps for March 15, 1979
from Brown et al. (2003) (left) and the KED method (right).

ACKNOWLEDGMENTS

The authors acknowledge René Roy (Hydro-Québec) for his support of this project and for his advice and useful discussions. Thanks are also extended to the MDDEP (Éric Larrivée and Pierre-Yves St-Louis) for supplying snow course and daily snow depth data to this project, and to Eva Mekis of the Climate Monitoring Section of Environment Canada for providing the CANGRD dataset.

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