RETROSPECTIVE GEOSTATISTICAL MAPPING OF SNOW WATER EQUIVALENT OVER QUEBEC

Nicolas JEANNEE[1], Dominique TAPSOBA[2], Ross BROWN[3]

[1] GEOVARIANCES, 49 bis, avenue Franklin Roosevelt, BP 91, F-77212 Avon (FRANCE) nicolas.jeannee@geovariances.com
[2] IREQ, Institut de Recherche d'Hydro-Québec (IREQ), Varennes, Québec (CANADA) Tapsoba.Dominique@ireq.ca
[3] ENVIRONNEMENT CANADA, Section des processus climatiques, Montréal, Québec (CANADA) Ross.brown@ec.gc.ca

BACKGROUND & OBJECTIVES

Snow accumulation over Quebec and adjacent Labrador is significant at a continental scale with annual maximum snow accumulations averaging 200-300 mm of snow water equivalent (SWE). This resource is vital for the economy of Quebec where a large fraction of the energy demand is met through hydro-electricity generation. 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. However, snow cover variability and change in this region of North America has not been thoroughly assessed due to spatial and temporal limitations in the available snow observing systems.

The main objective of the project is to generate gridded historical SWE maps over Quebec at a high resolution (10km x 10km) using elevations derived from 1km DEM as covariate in order to:

- provide a high quality dataset to investigate the spatial and temporal variability in SWE over Quebec,
- improve the monitoring of SWE anomalies over Quebec hydro-electrical generation basins.

The added value of the developed methodology is illustrated and discussed in the context of the operational implementation of the system by Hydro-Quebec for monitoring water inflows to hydropower reservoirs and evaluating climate models.

AVAILABLE DATA

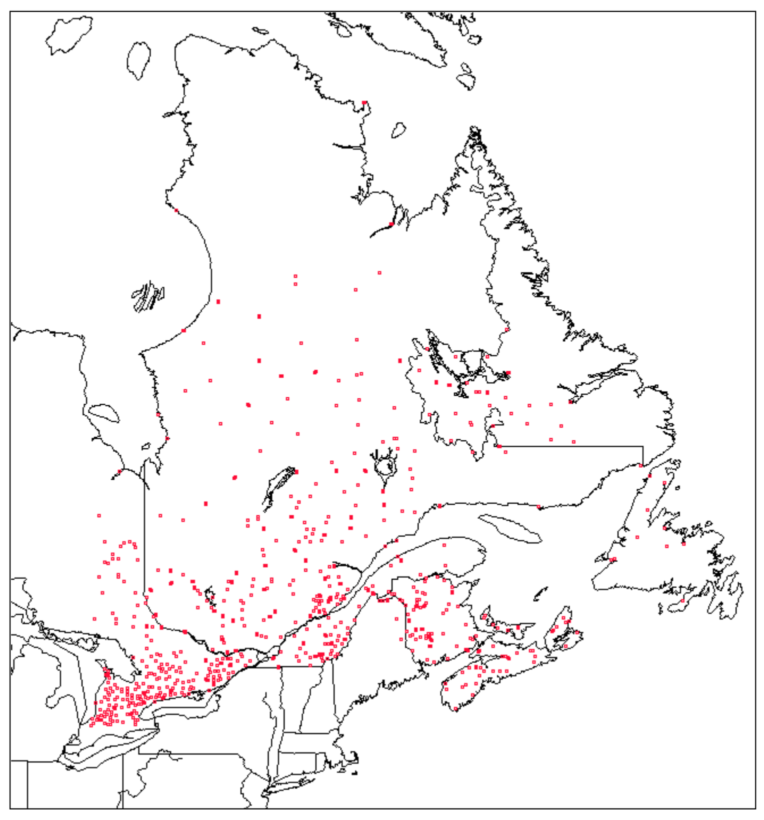
Extensive data are available from about the mid-1960s but the observations tend to be concentrated over southern Quebec.

The main data source for SWE observations was the historical snow course compilation for Canada prepared by the Meteorological Service of Canada in 2000 supplemented with the Quebec snow course database maintained by the Quebec government (MDDEP) which includes observations from Hydro-Quebec, Alcan, and the Churchill Falls Power Corporation. 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.

Daily ruler measurements of the depth of snow on the ground are available from Canadian synoptic and climate stations and usefully supplement the snow course observations.

Acknowledgments to data providers:

- Hydro-Québec
- Ministère du Développement durable, de l'Environnement et des Parcs
- Ontario Ministry of Natural Resources
- New Brunswick Environment
- NOAA (NCEP reanalysis)
- EC Climate Data Analysis Section (CANGRD precipitation product)

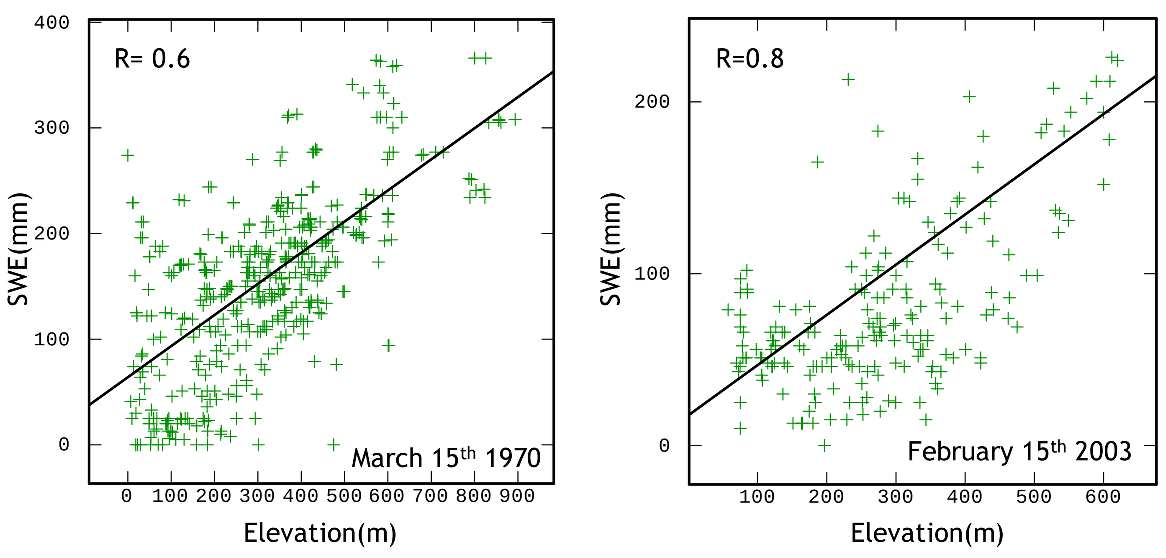


Location of the snow course observations over the area of interest (complete observations of the 1970s).

GEOSTATISTICAL METHODOLOGY

1. Multivariate analysis

There is a strong relationship between topography and SWE. Linear correlation coefficients between SWE and topography over the 1970-2005 period are greater than 0.6.



2. External Drift Kriging approach

External drift kriging (EDK) is a classical approach that aims at integrating, in the modeling of a target variable $Z(x)$, the knowledge of an auxiliary field $s(x)$ linearly correlated with $Z(x)$, $s(x)$ providing a large scale information about the spatial trend of $Z(x)$. EDK only requires the kwnoledge of the variogram of the residuals (see e.g. Chilès & Delfiner, 1999).

In the case of the snow water equivalent (SWE), EDK at a given location x relies on the following decomposition:

$$SWE(x) = D(x) + R(x)$$

with:

– $D(x)$ derived from topography $T(x)$:

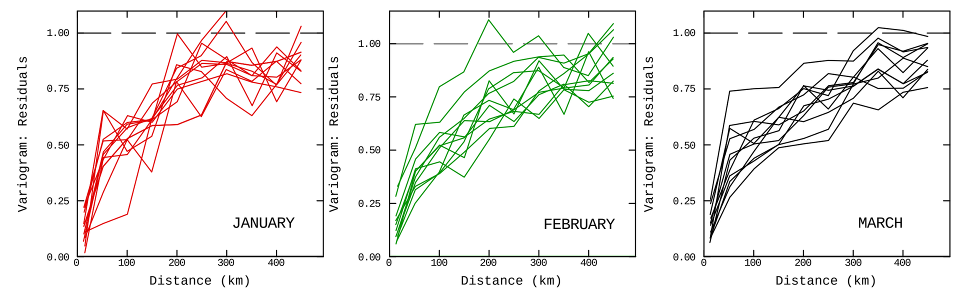
$$D(x) = a.T(x) + b$$

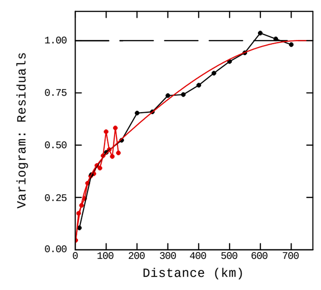
– $R(x)$ stationary residuals with mean 0.

To ensure robustness of the temporal SWE estimates, a constant variogram model is assumed for each season, fitted on average experimental variograms derived from the 1st and 15th of every month from December to May for the period from 1970 to 2005.

3. SWE spatio-temporal variability

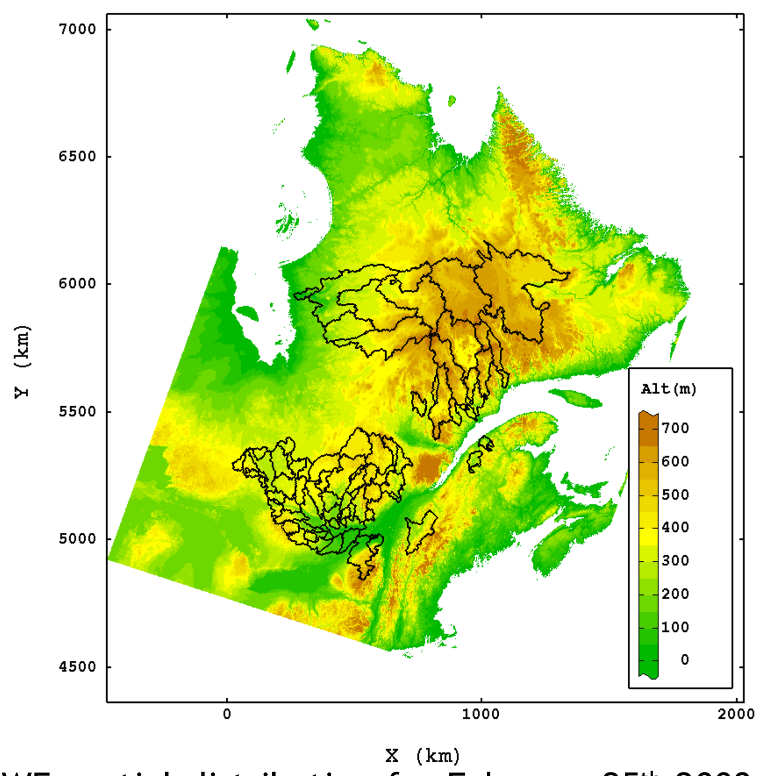
Example of normalized variograms of residuals from SWE regression with topography (1970-1980).
No significant differences between monthly variograms.

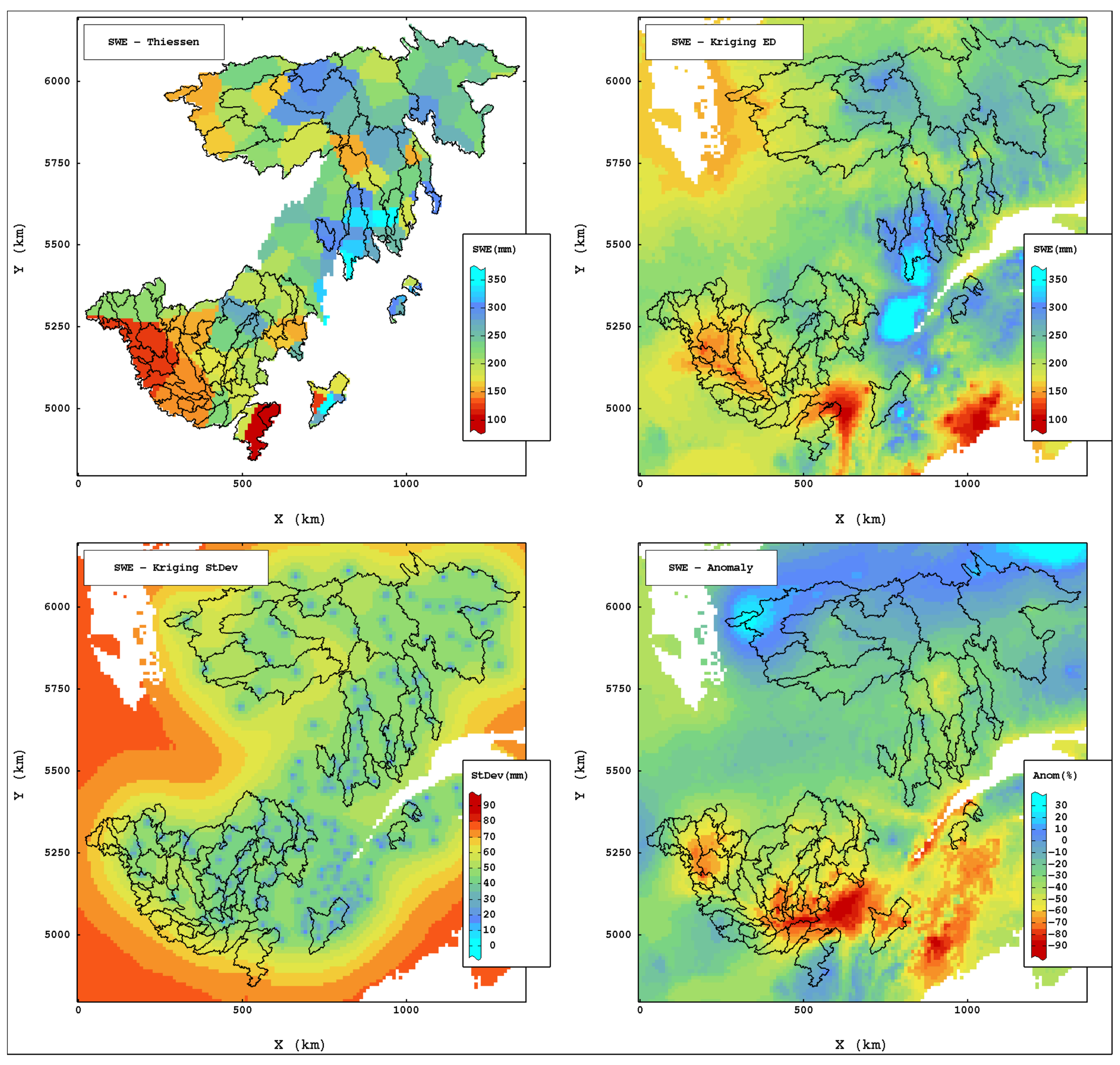




Combined use of two experimental variograms focusing on small and large distances for variogram fitting.
Choice of a variogram model based on two spherical nested structures

RESULTS & VALIDATION





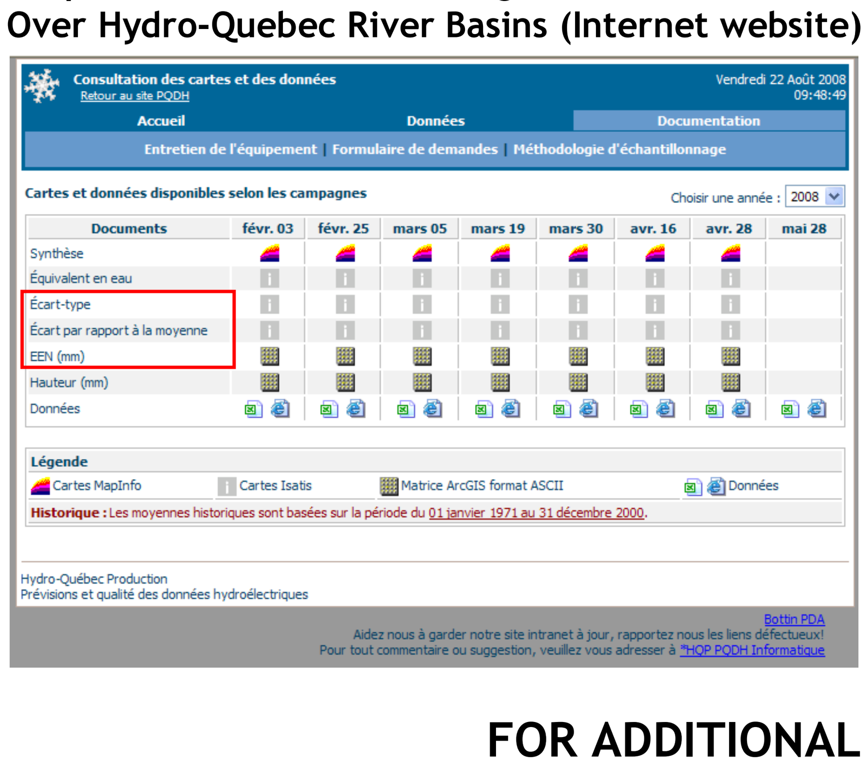
Maps of SWE spatial distribution for February 25th 2008 over Hydro-Quebec River basins: polygonal technique, SWE estimate using elevation (above) as external drift, standard deviation, anomaly in % (value *minus* reference period 1971-2000).

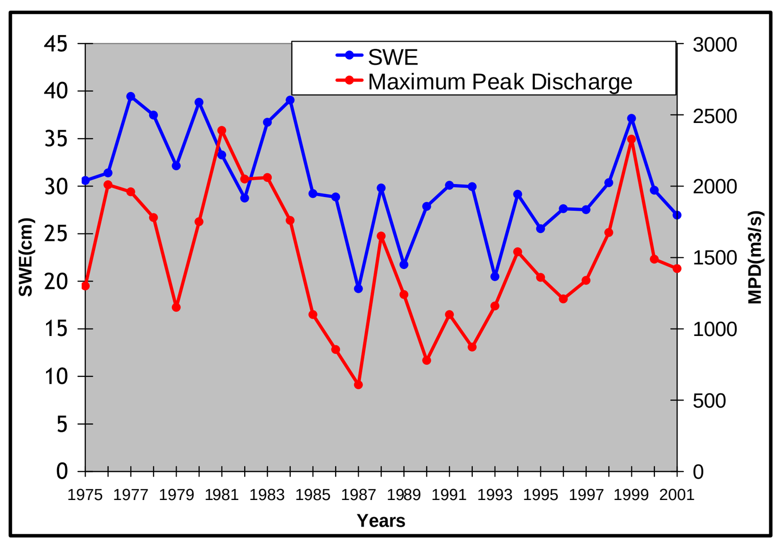
EDK shows a realistic spatial structure consistent with the structure of DEM but with SWE values honouring observation sites. Polygonal technique was formerly used to generate Hydro-Quebec forecasts. This technique was just based on the influence zone of each SWE measurement, without no additional information and any uncertainty estimate.

For operational run-off and streamflow forecasts, the maximum SWE grid map generated prior to the on-set of the spring snowmelt is used to assess the a priori potential for getting large run-off and floods. It could also be used to update the snow-related state variables related of our hydrological models, which forecast water inflows into the reservoirs during spring.

Snow anomaly maps have a significant impact on water availability. SWE anomalies maps are generated automatically be-weekly from December 1st to provide timely and geographic pattern of SWE to assist decision-making related to water management for Hydropower generation.

Graphical User Interface Design for SWE estimation Over Hydro-Quebec River Basins (Internet website)





The basin (Churchill) average snow water equivalent provided by EDK shows a strong correlation with the magnitude of maximum peak discharge in Fall. SWE is then incorporated as covariate into one or more of the parameters of the Generalized Extreme Value (GEV) distribution to improve extreme flood modeling for dams design.

Differences (mm) on SWE maximum mean over the 21 river basins of Quebec (time period 1979-1999) between the Canadian Regional Climate Model (RCM) simulation and the geostatistical estimate. The consistency between RCM forecast and SWE estimates with EDK contributes to validate the RCM forecast.

CONCLUSIONS & PERSPECTIVES

- This study suggested that topographic control on the redistribution of snow has significant influence on spatial snow distribution. Runoff forecasting can be improved by integrating elevation as external drift.
- Although SWE interpolations are influenced by data availability, integrating topography is useful for predicting stream flow. The presented methodology provides water managers with more accurate volumes of water stored in snowpack.
- Future challenges include the investigation of alternative interpolation methods as well as the integration of additional covariates e.g. vegetation characteristics (vegetation density and tree type play an important role in sublimation loss).

FOR ADDITIONAL INFORMATION

- Geostatistical computations performed using **Isatis®** 8.0 software developed by Geovariances (http://www.geovariances.com)
- Caya, D., and R. Laprise, 1999: A Semi-Implicit Semi-Lagrangian Regional Climate Model: The Canadian RCM. *Mon. Wea. Rev.*, **127**, 341-362.
- Music, B., and D. Caya, 2007: Evaluation of the Hydrological Cycle over the Mississippi River Basin as Simulated by the Canadian Regional Climate Model (CRCM). J. Hydromet., 8(5), 969-988.
- Brown, RD, Brasnett B, Robinson D. 2003. Gridded North American monthly snow depth and snow water equivalent for GCM evaluation. *Atmosphere-Ocean* **41**: 1-14.
- Tapsoba, D, Fortin V, Anctil F, Haché M. 2005. Apport de la technique du krigeage avec dérive externe pour une cartographie raisonnée de l'équivalent en eau de la neige : Application aux bassins de la rivière Gatineau. *Can. J. Civil Engineering* **32**: 289-297.