7.12 DERIVATION OF AN IMPROVED SNOW WATER EQUIVALENT ADJUSTMENT FACTOR MAP FOR APPLICATION ON SNOWFALL RULER MEASUREMENTS IN CANADA

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1. INTRODUCTION

The depth of freshly fallen snow measured by ruler has been the standard measurement of snowfall since Canadian snowfall measurements began. For all stations, prior to the 1960's, and for most non-synoptic stations over the entire record, total precipitation (water equivalent) for snowfall events is determined by assuming a density for freshly fallen snow of 100 kg m^{-3}. At synoptic stations, a Nipher shielded snow gauge was introduced in the 1960's to directly measure snow water equivalent for determination of precipitation amount, but depth of snowfall measurements with a ruler were continued. The adjustment of ruler measurements to be homogeneous with Nipher gauge data would raise a number of difficulties, including that of the snow density in the past. The limiting factor for the use of Nipher shielded snow gauge data is its restricted availability both in time (Nipher gauges were first installed in the 1960's) and space (there are almost 10 times more ruler measurement stations). As well, inherent to the Nipher measurements are all the problems associated with gauge undercatch due to wind and wetting loss. Because the process of ruler measurement has undergone fewer changes over time, the use of daily snow ruler data is more appropriate for climate change studies. The focus of this study is to produce the Canada-wide map for the Snow Water Equivalent Adjustment Factor (SWEAF), which could be applied on any snow ruler measurements available for over 2000 locations across Canada.

In several climate related projects it is important to compute the correct water equivalent value of the measured freshly fallen snow. For the computation of snow water equivalent the use of the standard density of freshly fallen snow is rejected. The use of the SWEAF map can provide appropriate snow water equivalent values suitable for hydrologic studies, for example.

The first version of the SWEAF map was published in Mekis & Hogg, 1999. Since then the importance of a more detailed and precise map was identified and the study was repeated on a wider scale including all possible stations and a search of their associated metadata. In the process of outlier identification, the expert opinions of climatologists at the MSC regions were also included.

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2. DATA AND METHODOLOGY

The snowfall water equivalent computation method follows Metcalfe et al. (1994) and is based on the ratio of adjusted Nipher gauge measurements to snowfall ruler depth measurements for all events greater than trace values during the period of record when snow ruler and Nipher gauge measurements were made coincidentally. The adjustment procedure accounts for gauge undercatch due to wind and for wetting and evaporation losses. Applying adjustments determined in this way, the ruler measurements can be adjusted as closely as possible to the true, long-term average, water equivalent of fresh snowfall. The rain gauge correction values originated from the publications by Metcalfe et al. (1997) and Routledge (1997).

Using the Canadian National Archive of Climatological Observations, all stations with hourly and synoptic programs were selected for the period 1960-2001 (321 stations were found). The applied condition was the co-existence of the six-hourly and daily precipitation measurements and the six-hourly wind measurements.

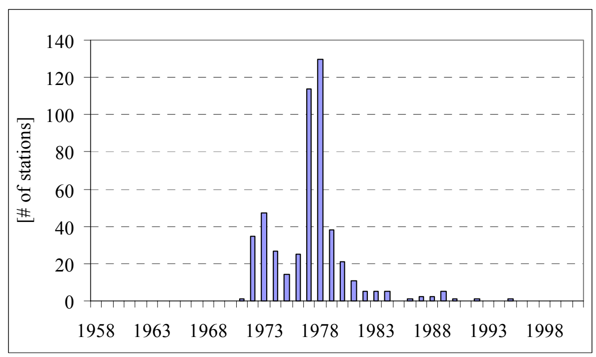

Figure 1a. Distribution of the Type B rain gauge installation year for 495 locations across Canada

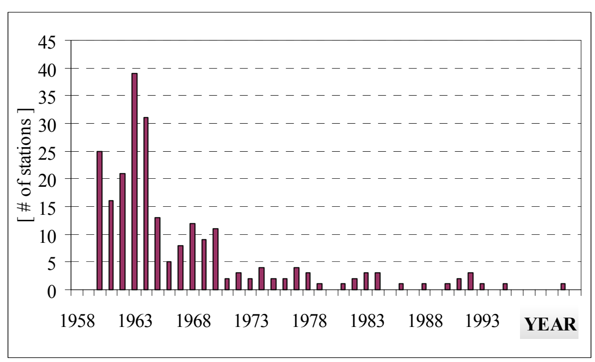

Figure 1b. Distribution of the Nipher gauge installation year for 233 locations across Canada

For the proper adjustment procedure, the following metadata information is required: precipitation gauge installation dates (Nipher gauge, MSC Type B rain gauge), anemometer height and wind exposure code. Metadata was collected mainly using the most detailed and accurate paper format of station inspection reports. The distributions of Type B and Nipher gauge installation years are plotted on Figures 1a and 1b.

The wind-related metadata is required for the proper adjustment of the Nipher gauge data for undercatch associated with windy conditions. Although the Nipher shield was designed to minimize the disturbance of airflow around the orifice to the gauge, Goodison (1978) demonstrated that the Nipher shield reduced the undercatch but did not eliminate it. Anemometer height is a highly variable value within the range of 5 to over 30 m. Beginning in the 1960s, anemometer heights were standardized to 10 m at most airports. Most Canadian stations now adhere to this standard. The most difficult task was to get wind exposure codes in each direction. All possible exposure codes applied in the study are listed in Table 1. Final exposure code is given by the average of all 4 directions at any station [Example: the final value on Figure 2 is (1+1+6+5)/4 = 3].

Table 1. Exposure code descriptions

Code	Description
1	open
2	flat, open
3	flat, open, small obstructions
4	small buildings or trees
5	buildings nearby, airport
6	buildings, tower, trees, hills
7	sheltered in all direction, on the top of building

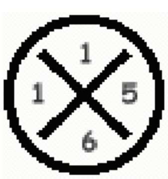

Figure 2. Exposure code example.

The sensitivity of different exposure codes on the SWEAF was studied for 50 stations (Figure 3). The result clearly shows that a small change in the exposure code does not have significant effect on the final results.

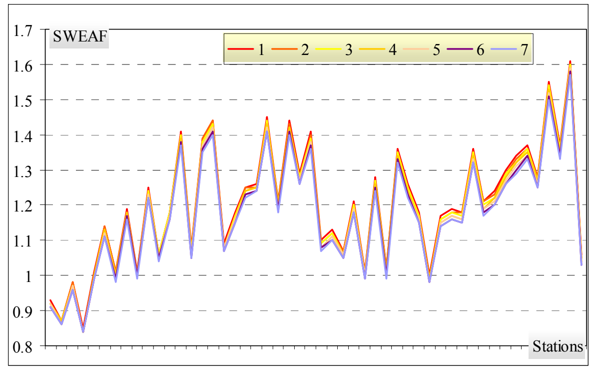

Figure 3. Effect of exposure codes on SWEAF for greater then trace precipitation events.

3. STATION SELECTION, SEARCH FOR OUTLIERS

After all the pre-required studies, the stations were classified based on the continuity of measurements and missing records. Different classes based on station quality and longetivity are introduced and tabulated (Table 2). The location of stations with over 20 years of data, additional stations with 15 to 20 years of data and the location of the original 63 stations used in the Mekis and Hogg, (1999) study are presented in Figure 4. It was decided that in the final map, only the best quality stations (stations with more then 20 years of continuous measurements) would be included.

Table 2. Flags used in station selection procedure.

O	0	Original 63 stations
*	1	Good quality data (with more then 20 years of data) – 179 stations
*	2	Data with 15 - 20 years of data – 40 stations
*	3	Data with 10 - 15 years of data (may be useful) – 27 stations
*	4	Not useful – 77 stations

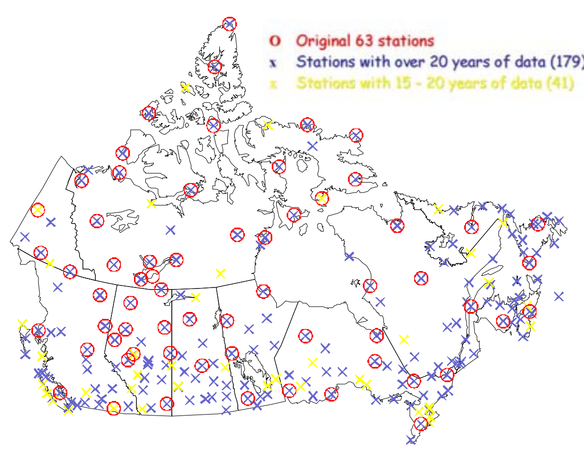

Figure 4. Station locations used in the SWEAF study.

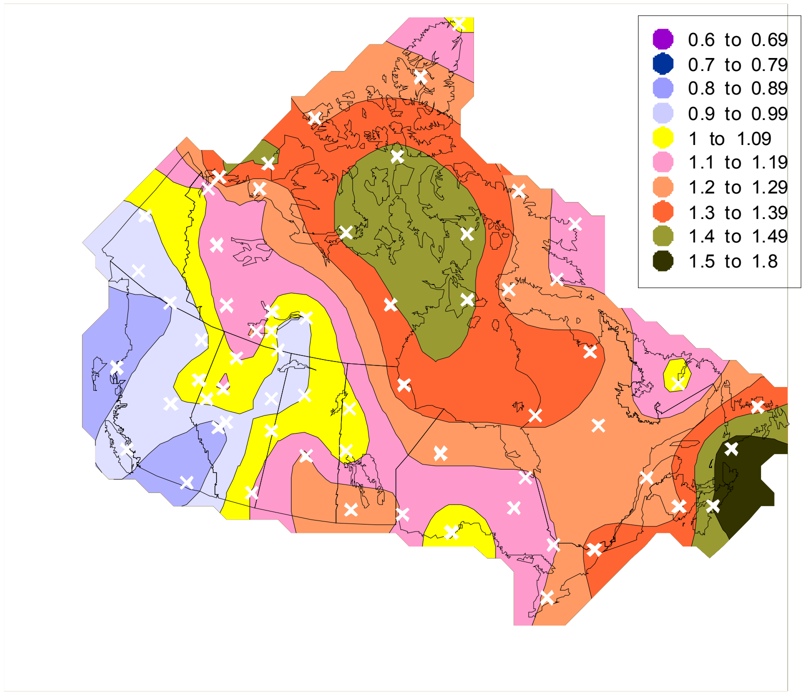

Figure 5. Original SWEAF map.

The SWEAF ratios are computed for each location for each greater than trace precipitation events. The final interpolated map was developed using Kriging with a linear variogram model. The applied resolution is 100 km, because no significant difference had been found for greater grid resolution computations (e.g. 50 km). The first version of contoured adjustment factor maps for greater than trace events is plotted in Figure 6. This map contains all 179 stations which qualified (met the requirement of more than 20 years of continuous measurements). The next step was the evaluation of the resultant contour map based on spatial consistency, in other words searching for outliers by comparing close-by stations. The locations mentioned in the paper below are also plotted on Figure 6.

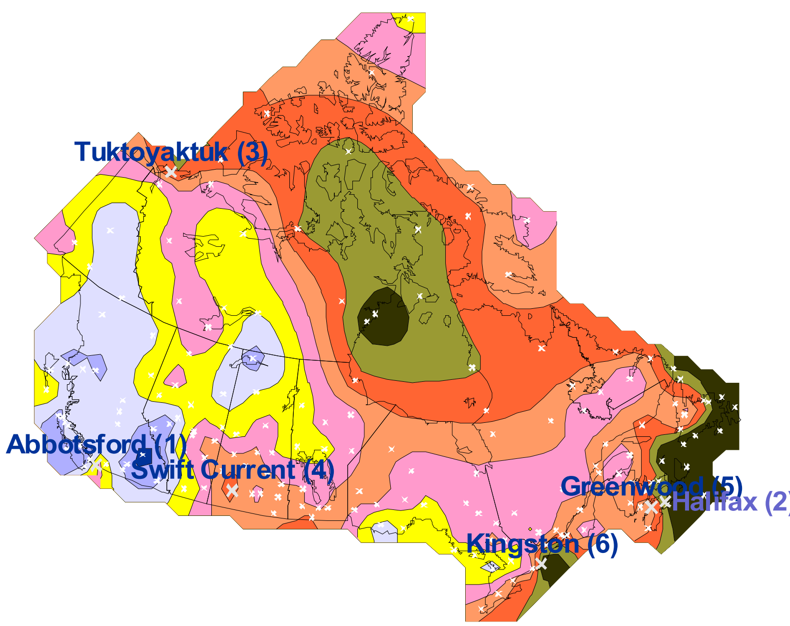

Figure 6. New SWEAF map with outliers included in the analysis.

(1) On the west coast *Abbotsford* was removed after careful comparison with two nearby locations Vancouver and Victoria.

(2) The anemometer heights at *Halifax* looked anomalous. After an extensive metadata search by a regional personnel it was revealed that the anemometer was not installed at the standard 10 m because of a local airport planning restriction. Because the metadata reflected the real situation, it was decided to retain this station in the SWEAF analysis.

(3) The situation with *Tuktoyaktuk* was less obvious. After the comparison of daily measurements from different resources, it turned out, that there was no Nipher program at this location so the station data could not be used for the SWEAF analysis. The station was removed from the final selection.

(4) The case of *Swift Current* is just the opposite. The reason of discrepancy between Moose Jaw and Swift Current is the probable use of Nipher gauge measurements to estimate snowfall measurements as well, for part of the observing period. For this reason, this station had to be removed.

(5) The relatively lower values at *Greenwood* compared to the area initiated a further metadata search. Greenwood has a good reputation for careful and consistent measurements. It is located in an area which receives a lot of "lake-effect" type snow from the Bay of Fundy, much like the area around the Great Lakes. The behaviour of this station compared to other locations in Nova Scotia is shown to be different. The station was kept in the final selection.

(6) *Kingston* in Ontario had to be removed as well. It is a clear outlier but the specific reason for its anomalous value could not be determined.

The final map after removing the outlier locations of Abbotsford, Tuktoyaktuk, Swift Current and Kingston is plotted on Figure 7.

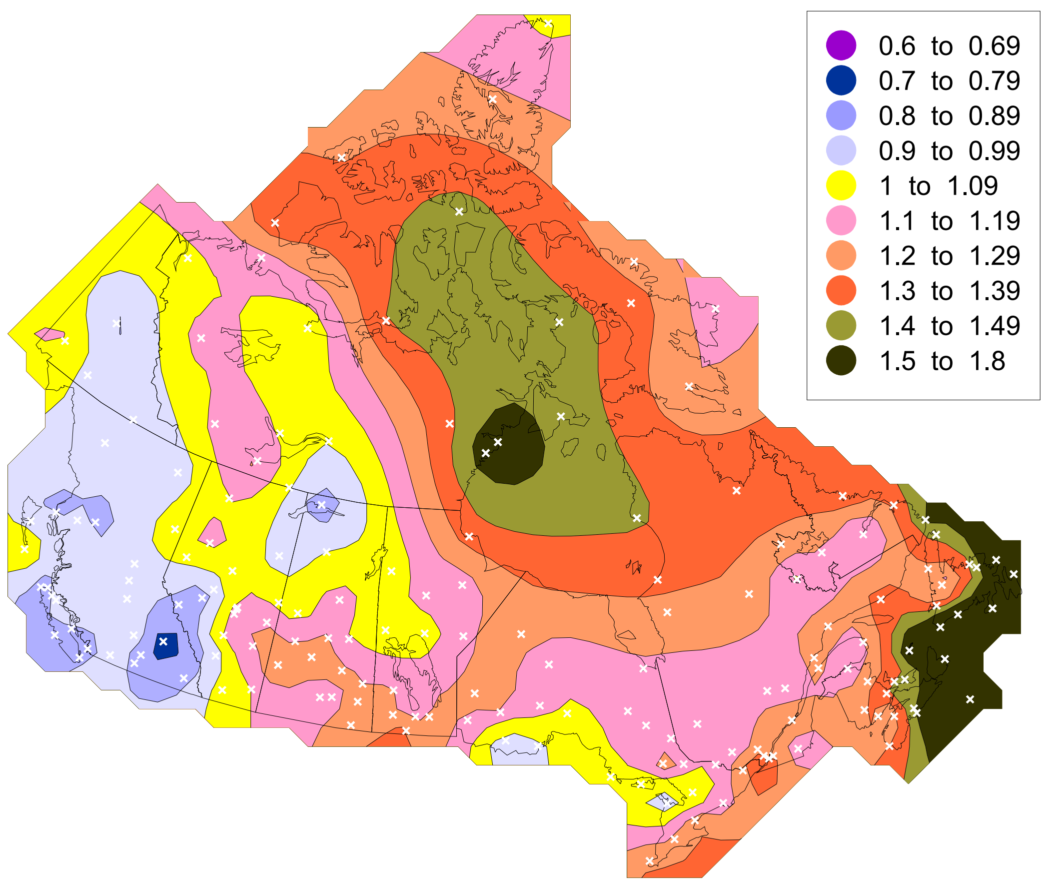

Figure 7. Final SWEAF map based on 175 locations across Canada.

4. CONCLUSIONS

A comparison of the original Figure 5 published by Mekis and Hogg, 1999 and a new SWEAF figure using the same 63 locations revealed some differences. It could be explained by the fact that the actual computation period became longer and the metadata were occasionally updated based on new evidence.

The major achievement of the improved SWEAF map is a higher station density, an extensive metadata search and a very thorough search for outliers. Using spatial interpolated data based on 175 locations across Canada, the SWEAF map provides an excellent tool to estimate realistic snow water equivalent from snowfall measurements. The resultant snow water equivalent estimates provide a good basis for several climate research studies, including climate change.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

Goodison, B.E., 1978. Accuracy of Canadian snow gauge measurements. *J Appl. Meteor.,* **27**, 1542-1548.

Mekis, É. and W. Hogg, 1999: Rehabilitation and Analysis of Canadian Daily Precipitation Time Series. *Atmosphere-Ocean*, **37**, 1, 53-85.

Metcalfe, J.R., S. Ishida and B.E. Goodison, 1994: A corrected precipitation archive for the Northwest Territories. Environment Canada - *Mackenzie Basin Impact Study, Interim Report*, **2**, 110-117.

Metcalfe, J.R., B. Routledge and K. Devine, 1997: Rainfall measurement in Canada: changing observational methods and archive adjustment procedures. *J. Climate*, **10**, 92-101.

Routledge, B., 1997: Corrections for Canadian standard rain gauges. *Environment Canada, Interim Report*, 8 pp.