Homogenization of Canadian In-situ Precipitation Data

Final Report of Contract KM040-09-1134

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Part 1

The work specified in the contract

1. Convert snowfalls to their water equivalents using the newly developed snowfall-water equivalent ratio map for Canada (Mekis and Brown, 2009), and correct the original measurements for gauge undercatch and evaporation due to wind effect, and for gauge specific wetting loss (Mekis and Hogg, 1999)
2. Use statistical methods to assess homogeneity of frequency series of various small precipitation measured and of trace precipitation reported, and develop a method to account for frequency discontinuities detected and use available metadata to verify the results of statistical test. Also need to consider treatment of other flags in the raw data archive.
3. Homogenize monthly total precipitation series, which include testing using appropriate statistical methods and estimating adjustments. Here, the focus will be on all precipitation of data since 1979 first.
4. Homogenize daily precipitation series (again testing and estimating adjustment). Here, the focus will be on long term stations first.

Adjustments made to the tasks

Searching metadata for information, such as rain gauge types and dates of replacements, is a key step for correcting the original measurements for gauge undercatch and evaporation due to wind effect and gauge specific wetting loss. Identifying observation times and their historical changes is also required for correcting trace precipitation amount. When I started to identify such information in metadata, I found that this process was very time-consuming. I realized that it would be much more convenient and effective to identify such information for all stations of precipitation data rather than only focusing on a small number of stations with long-term data first. After discussing with the Scientific Authority Dr. Xiaolan Wang, the work was adjusted to find relevant metadata information for all stations of precipitation data (approximately 7500 stations were processed) and to complete gauge-related corrections for all data, which goes back to 1840s at some stations, rather than only since 1979 in the contract. These changes increased the overall effectiveness of the project and benefited other related on-going project (such as the blending precipitation project). However, the new tasks were much more time-consuming, and they required more than three times of the originally estimated time to complete. Homogeneity tests for frequency series of trace flags and small amount precipitation events were also performed for all stations with applicable corrections rather than stations only with long-term data (there are about 500 stations of data for 30+ years). Thus, verification of changepoints with metadata and adjusting daily precipitation data, originally specified in the contract, were initiated but could not be completed within the contract period. These changes were approved by the Scientific Authority before being made. These are all to the benefit of Environment Canada.

Since monthly total precipitation series derived from homogenized daily precipitation series can be considered homogenous, homogenization of daily precipitation series is of the ultimate priority and has become a focus of the contract work, with only some experimental work being done in testing homogeneity of monthly total precipitation series. Homogenizing daily precipitation series and then deriving monthly precipitation series from homogenized daily precipitation series could maintain the consistency between daily and monthly precipitation series.

In addition to the work specified in the contract, some other closely related work was done, upon Dr. Xiaolan Wang's request, such as computing mean intensity of daily precipitation, especially processing hourly precipitation data from the Hydro Quebec archive. Processing the Hydro Quebec precipitation data took me plenty of time because such data are in a very different format from the data in the Environment Canada archives. These Hydro Quebec data were needed and used for the blending precipitation project. This task also falls in the expansion of the station list (from a limited number of long-term stations to all stations of available precipitation data).

Part 2

Summary of the work and outputs

1. Data availability in the archives

Station lists were compiled for stations with precipitation data from 1979 onwards in Environment Canada Daily Climate Data Archives (including DLY04 E010, E011, E012; DLY02 E010, E011, E012; and DLY44 E010, E011, E012). The lists were presented in the following files under folder '\stationlist\' on the data storage disk.

stationlistDLY02E010new1979.xls
stationlistDLY02E010new197910y.xls
stationlistDLY02E011new1979.xls
stationlistDLY02E011new197910y.xls
stationlistDLY02E012new1979.xls
stationlistDLY02E012new197910y.xls
stationlistDLY04E010new1979.xls
stationlistDLY04E010new197910y.xls
stationlistDLY04E011new1979.xls
stationlistDLY04E011new197910y.xls
stationlistDLY04E012new1979.xls
stationlistDLY04E0120new197910y.xls
stationlistDLY44E0101979.xls
stationlistDLY44E0111979.xls
stationlistDLY44E0121979.xls

A station list for all available stations in Environment Canada Daily Climate Data Archives DLY02, DLY04, DLY44, AB Environment, Manitoba, and RMCQ was also compiled. The list, together with the values of SWE adjustment factor and ICR values, kindly provided by Dr. Eva Mekis of Environment Canada for each station, can be found under '\stationlist\ SWE_&_ICR_8562.xls'.

2. Frequency information

Annual frequencies of flags in daily precipitation data, precipitation observation numbers, monthly and annual frequencies of trace precipitation events were computed, for stations with records for at least 10 years since 1979 in Climate Archive DLY04E012 (2877 stations in total) under the folder '\DLY04E012freqflag79y10\' (a total of 8631 text files).

3. Snow water equivalents

Snowfall amounts have been converted to their water equivalents by multiplying the SWE adjustment factor at each station developed by Dr. Eva Mekis, for all the E011 snowfall data in the Environment Canada Daily Climate Data Archives as shown in Table 1.

Table 1. Summary of snow water equivalents conversion*

Data file folder	Number of stations being converted	Number of stations in the Archive
DLY02E011SWE[1]	591	981
DLY04E011SWE[2]	7489	7490
DLY44E011SWE	647	647

[1]DLY02E011: The remaining 390 stations contain only missing data.
[2]DLY04E011: No SWE factor was available for conversion for Station ID 8401000.
*Output format can be found in file 'format.xls'.

4. Correcting original measurement for gauge undercatch and evaporation due to wind effect, and for gauge specific wetting loss

A lot of time was spent to identify rain gauge types and their associated dates of installation and replacement at each station from the precipitation metadata in hand, as such information is the basis for applying rain gauge corrections related to undercatch and evaporation due to wind effect and gauge specific wetting loss by the use of the correction procedure proposed by Mekis and Hogg (1999). Identifying rain gauge types and changing dates from precipitation metadata is a very time-consuming task. There are two EXCEL sheets containing rain gauge information in the metadata database provided by EC: the ‘precipitation’ sheet contains information for 423 stations and the other one ‘Precipitation_related_Metadata’ for 3470 stations. Rain gauge information was available for most stations but not all the stations as it can be seen in Table 2.

Table 2. Summary of precipitation metadata

Metadata sheets	Number of stations with identifiable rain gauge types and changing dates	Number of stations without identifiable rain gauge types or changing dates or "auto" rain gauge types
precipitation	376*	47
Precipitation_related_Metadata	3010	384

*Including the same 76 stations being found in both ‘precipitation’ and ‘Precipitation_related_Metadata’ sheets in the metadata database. These 76 stations were counted for the ‘precipitation’ sheet only.

A total of 3386 stations have identifiable information for rain gauge types and their associated start and end dates at each station from the available precipitation metadata. There are 3384 stations in the archive DLY04E010. Two stations (IDs 1018FJ5 and 810I001) were found in the archive DLY02E010 with all missing data.

Rain gauge related corrections were applied to daily rainfall amounts for all identified rain gauge types, based on available information following Mekis and Hogg (1999). Rain gauge corrections were applied to daily rainfall amounts in daily archive DLY04E010 for 3384 stations and were saved in new data files for further processing as shown in Table 3.

Table 3. Summary of rain gauge related corrections

File folder	Number of stations
DLY04E010DRGM79y*	2145
DLY04E010DRGMother**	1239

*E010DRGM79y contains daily rainfall amounts with rain gauge corrections for stations with at least 10-year long records (may include missing data) since 1979.
**Daily rainfall amounts for all other stations in this folder were applied with rain gauge type corrections.
See file 'format.xls' for data format.

The necessary adjustment associated with instrument changes for daily rain gauge measurement can be summarized as:

$date_1$ $date_2$

	MSC Copper liner	MSC Plastic liner	Types – B	
	---------------------○	●------------------------------○	●------------------	
"measured"	× 1.04	× 1.04	× 1.02	gauge undercatch
	+ 0.02 [mm]	+ 0.03 [mm]	+ 0.01 [mm]	evaporation
	+ 0.19 [mm]	+ 0.16 [mm]	+ 0.11 [mm]	retention

It is difficult, sometimes, to find rain gauge types from the limited metadata as rain gauge information is neither clear nor consistently recorded. Some general rules for determining the rain gauge type in use at a time were set with advices provided by Dr. Eva Mekis. These rules, being followed in the rain gauge related corrections, are listed below.

Rules for identifying rain gauge type:

1. Unless there are clear indications for other types of rain gauge, corrections for MSC Copper gauge will be applied to daily rainfalls for the time period up to 1964-12-31. (Apply the first type of correction for the whole record backwards from 1964)
2. Corrections for MSC Plastic liner will be applied to daily rainfalls for the time period from 1965-01-01 to the documented date of Type-B gauge installation, even if MSC plastic was not documented or ‘standard’, ‘ordinary’ and ‘unknown’ in the metadata. If there is a given date for the MSC plastic installation (instead of the copper), then the documented date should be used. Otherwise, corrections for MSC plastic liner would be applied from 1965-01-01.
3. Corrections for Type-B gauge will be applied to daily rainfalls from the documented Type-B gauge installation date to the record end unless other type of rain gauge could be identified from the metadata.
4. No corrections will be applied if a very different type of rain gauge (such as the ‘US 8’ rain gauge) is documented.

5. Frequencies of small precipitation amounts and of trace precipitation flags

Daily rainfall amounts that were corrected for rain gauge related biases, such as wetting loss and evaporation, were combined with daily snow water equivalents to form new daily precipitation data series for all available stations. Time series of monthly relative frequencies of various small precipitation amounts measured (e.g., <=0.3mm, 0.3-0.5mm, 0.5-1.0mm, 1.0-2.0mm and 2.0-3.0mm), and of trace precipitation flags have been calculated from the new daily precipitation data series. It may be worthwhile to mention that a monthly frequency was calculated only if there were at least 15 days (14 days for February) with a valid observation, otherwise a missing value was assigned to the monthly frequency in all classes for the month.

As it could be noticed, there are three categories of stations in daily precipitation archives, based on the availability of data. Details of these three categories can be found in Table 4. Results are stored and presented for each category.

New daily precipitation data series are stored under file folders ‘DLY04E012RS79y’ (for Category a), ‘DLY04E012RSother’ (for Category b), and ‘DLY04E012S4100’ (for Category c). Data formats for these data series are listed in ‘format.xls’.

Table 4. Three categories of stations in daily precipitation archives

Category	Number of stations	Description
a	2145	With at least 10-year data since 1979 regardless in which years the data start and end, rain gauge related corrections being applied and snowfalls being converted to their water equivalents using new SWE factors.
b	1239	With less than 10-year data since 1979 regardless in which years the data start and end, rain gauge related corrections being applied and snowfalls being converted to their water equivalents using new SWE factors.
c	4100	All other stations, rain gauge related corrections could not be applied but snowfalls being converted to their water equivalents using new SWE factors.

The PMFred algorithm in the RHtest package was performed to identify changepoints in the monthly frequency series whenever it was applicable. Results were summarized in 'Report 2010-2011'. Test results are stored under file folder 'DLY04E012RStest' with details shown in Table 5.

Table 5. Summary of homogeneity test results for frequencies of small amount precipitation

File folder	Sub-file folder	Sub-file folder
DLY04E012RStest	output79y	output0.5-1.0mm79y
		output0.5-1.0mmretest79y
		output1.0-2.0mm79y
		output1.0-2.0mmretest79y
		output2.0-3.0mm79y
		output2.0-3.0mmretest79y
		output0.0-0.3mm79y
		output0.0-0.3mmretest79y
		output0.3-0.5mm79y
		output0.3-0.5mmretest79y
		outputtrace79y
		outputtraceretest79y
	outputother	output0.5-1.0mmother
		output0.5-1.0mmretestother
		output1.0-2.0mmother
		output1.0-2.0mmretestother
		output2.0-3.0mmother
		output2.0-3.0mmretestother
		output0.0-0.3mmother
		output0.0-0.3mmretestother
		output0.3-0.5mmother
		output0.3-0.5mmretestother
		outputtraceother
		outputtraceretestother
	outputS4100	output0.5-1.0mmS4100
		output0.5-1.0mmretestS4100
		output1.0-2.0mmS4100
		output1.0-2.0mmretestS4100
		output2.0-3.0mmS4100
		output2.0-3.0mmretestS4100
		output0.0-0.3mmS4100
		output0.0-0.3mmretestS4100
		output0.3-0.5mmS4100
		output0.3-0.5mmretestS4100
		outputtraceS4100
		outputtraceretestS4100

6. Estimating and correcting trace precipitation amount for each trace flag

Estimating precipitation amounts associated to trace precipitation events involves both trace rainfall and trace snowfall events. According to Mekis and Hogg (1999), the trace rainfall adjustment factor is associated with number of precipitation observations taken in a day. The massive work related to trace precipitation adjustment is to identify the number of daily precipitation observations at each station and the temporal evolution of daily observation numbers from metadata. As metadata is not complete, the historical evolutions of daily observation times at many stations could not be clearly identified. I consulted Dr. Eva Mekis on estimating and correcting trace amounts, in order to keep the results consistent with Mekis and Hogg (1999). Solid trace precipitation often occurs as ice crystals when air temperature is very low, especially at high latitudes. Ice crystals usually contain little water, thus the ratio of ice crystal events to the total trace events (ICR) is needed for assigning a specific amount to a trace event. ICR increases toward higher latitudes. Mekis and Hogg (1999) obtained ICR distribution from experimental data. Spatial interpolation is required to distribute ICR values from limited stations to all stations in the archives, for the purpose of assigning a definite precipitation amount to each trace event. ICR values were kindly provided by Dr. Eva Mekis for relevant stations.

The methods used to estimate and to correct trace precipitation amount for each trace flag reported are as the follows.

The adjustment associated with trace observations for daily rain gauge measurement can be summarized below:

$P = trace_1 \times T_{or,12}$ when the number of observation times is 2, $T_{or,12}=1.50$

$P = trace_1 \times T_{or,8}$ when the number of observation times is 3, $T_{or,8}=2.25$

$P = trace_1 \times T_{or,6}$ when the number of observation times is 4, $T_{or,8}=3.00$

P is adjusted daily amount of trace rainfall; $trace_1$ is 0.1 mm.

The adjustment associated with trace observation for daily rain gauge measurement was applied only to the stations with daily 2-, 3- or 4-times observations (including any combination of these observation times) if such information could be derived from metadata. These three numbers (2, 3, 4) of daily observation times are called "valid" observation times hereafter.

A total of 2600 stations were identified with "valid" observation times in the metadata. Adjustments were applied to 2520 stations identified in these two metadata sheets with "valid" observation times, including one station (ID 701S001) in the Archive DLY02E010. The result of rainfall trace adjustment can be found under file folder ‘DLY04E010trace’, and the output format is listed in ‘format.xls’. No trace flags were recorded at the remaining 80 stations of the above-mentioned 2600 stations. The station IDs of these 80 stations can be found in files ‘DLY04E010trace\flagnotraceDLY02E010’ (a total of 14 stations) and ‘DLY04E010trace\flagnotraceDLY04E010’ (a total of 66 stations).

Other stations without ‘valid’ observation times were found in the metadata with records such as 1 or 5, 6, 8 observation times, or ‘hourly’, ’15 minutes printout’, or ‘auto’, etc., or even no any information about observation times could be found in the metadata.

The actual snowfall trace adjustment due to the effect of ice crystal events was given by:

$$trace_2=0.07-[ICR\%-40\%]\times(0.07-0.03)/(70\%-40\%) \quad \text{for ICR>40\% events}$$

$$=0.07 \quad \text{for ICR}\leq\text{40\% events,}$$

where the Ice Crystal Ratio (ICR) is the fraction of ice crystal events to solid precipitation trace events.

The adjustments associated with daily snowfall ruler data with trace observations for daily snowfall ruler measurement (E011) can be summarized below:

$P=trace_2 \times T_{or,12}$ when the number of observation times is 2, $T_{or,12}=1.50$

$P=trace_2 \times T_{or,8}$ when the number of observation times is 3, $T_{or,8}=2.25$

$P=trace_2 \times T_{or,6}$ when the number of observation times is 4, $T_{or,6}=3.00$

P is the adjusted amount of trace precipitation for snowfall; $trace_2$ was developed by Mekis and Hogg (1999).

The adjustment associated with trace observations for daily snowfall ruler measurements was applied only to the stations with "valid" observation times (i.e., daily 2-, 3- or 4-times observations and any combination of these observation times) if such information could be derived from metadata, the same as for the treatment of daily rain gauge trace measurements. Finally adjustment was applied to 2584 stations identified in the metadata with "valid" observation times, including 77 stations without trace flags in daily archive DLY04E011. The results of snowfall trace adjustment for 2507 stations can be found under file folder ‘DLY04E011trace’, together with data format listed in ‘format.xls’. The station IDs of the other 77 stations without any trace flags reported are listed in the file ‘DLY04E011trace\flagnotraceDLY04E011’ (a total of 77 stations).

7. Adjustment for other reported flags

The same method was used in the adjustment for daily rain gauge measurements and snowfall ruler measurements with other flags. These flags were treated using the method described in Hopkinson (2005) as the follows.

Flag E as estimated values were treated the same way as values with blank flags for the purpose of this study. At some time someone has made a valid estimation and it seemed reasonable to utilize those estimates.

Flag M was treated as missing;

Flags C, L, A and F are grouped as accumulation flags.
C flag – Precipitation occurred, amount uncertain; value is 0;
L flag – Precipitation may or may not have occurred; value is 0;
A flag – Accumulated amount; previous value C or L for element 010,011or 012;
F flag – Accumulated and estimated.

Considerations in flag treatment are as the follows.

A value with a C or L flag followed by a non-zero value with a blank or E flag – it was apparent that the A flag was omitted in the case of a blank flag or incorrectly assigned in the case of an E flag so an A flag was inserted in place of the blank or E flag for subsequent processing.

A value or series of values with C and/or L flags was followed by a missing value – there is no way to reconcile a missing value and C or L flags. Therefore all value with a C or L flag leading up to the missing value were likewise set to missing.

A value with a C or L flag followed by a zero value and a blank flag – again the C and L flags are incompatible with a zero and a blank flag by definition. Therefore the values with a C or L flag were set to missing.

Occasionally there was an A or F flag not preceded by a C or L flag. In those cases, the value with the A or F flag was set to missing.

The typical entry in the archive is 0C on one day followed by a non-zero value with an A flag on the next. However, there can be a series of 0C and/or 0L values followed by a nonzero value with either an A or an F flag. Events longer than 4 days were set to missing.

For all other situations with accumulation flags in addition to the cases mentioned above, the following method was applied.

It was proposed that the distribution of precipitation over the accumulation period be estimated from the distribution of precipitation at neighbouring stations with a radius of 100 km. The total precipitation at each of the neighbouring stations was determined for the period in question and then the daily amounts expressed as a fraction of the total. An inverse square weighting scheme was employed to emphasize the closest station and give lesser weight to those further away. If there were no stations with valid data with 100 km, then values for all of the days in the accumulated event were set to missing. If precipitation at a neighbouring station was also accompanied with a flag (except E flag), this station was not used as a neighbouring station for this purpose.

Based on the procedures described above, all flagged rainfall amounts (other than trace) were processed for a total of 2257 stations in DLY04E010 where trace adjustment was applied. No adjustment was required for other 328 stations as no flags E, C, L, A, and F were reported at these stations in daily archive DLY04E010. These 328 stations are listed in the file 'DLY04E010flag\noflagsDLY04E010'. Adjustment for other flags was not applied to 15 stations in DLY02E010 as too many missing data at these stations. Rainfall data with adjustment for other flags (except trace flags) are stored under file folder 'DLY04E010flag' with their relevant format in 'format.xls'.

All flagged snowfall amounts (other than trace) were processed for a total of 2584 stations (including 439 stations without any other flags) where trace adjustment was applied. Snowfall data with adjustment for other flags (except trace flags) can be found in file folder 'DLY04E011flag' (total 2145 stations), and the data format is listed in 'format.xls'. No adjustment was needed for the 439 stations without flags E, C, L, A, and F in DLY04E010 and these stations are listed in file 'DLY04E011flag\noflagsDLY04E011'.

8. Comparisons of homogeneity test results for monthly frequencies of small amount precipitation events in raw data and "corrected" data

Comparisons were conducted to verify how the conversion of snowfall to water equivalents, trace corrections and rain gauge related corrections might have affected the homogeneity test results for monthly relative frequencies of various small precipitation amounts measured (e.g., <=0.3mm, 0.3-0.4mm, 0.4-0.5mm), based on raw (untreated original archived data) and new precipitation data with various "corrections" applied to the archived data. Based on the availability of data, details of these four categories (treated or processed at different stages for analyzing the effects of the treatments on data homogeneity) can be found in Table 6. Results were presented in 'Report 2011-2012'. A total of 500 stations with relatively long data series were selected from the datasets and presented separately (also see 'Report 2011-2012').

The PMFred algorithm (Wang, 2008) in the RHtests package (Wang and Feng, 2010) was performed to identify changepoints in the monthly frequency series whenever it was applicable. Results for frequencies of various small precipitation amounts measured (e.g., <=0.3mm, 0.3-0.4mm, 0.4-0.5mm), and of trace precipitation flags for precipitation data in Category 4 were summarized in ‘Report 2011-2012’. It was also performed to identify changepoints in the monthly frequencies series of small precipitation amounts (e.g., 0.3-0.5mm, 0.5-1.0mm, 1.0-2.0mm, 2.0-3.0mm) for data in Categories 1, 2, and 3.

Table 6. Four categories of stations for RHtest in daily precipitation archives

Category	Number of stations*	Description
1	2118**	Daily precipitation amount comes from DLY04E010 and DLY04E011. Daily rain gauge related corrections applied, snowfalls converted to water equivalents, and trace and other flags in the data archive treated.
2	2118	Daily precipitation amount comes from DLY04E010 and DLY04E011. Trace and other flags in the raw data archive treated.
3	2118	Daily precipitation amount comes from DLY04E010 and DLY04E011. Daily rain-gauge related corrections applied and snowfalls converted to water equivalents in the raw data archive.
4	2118	Daily precipitation amount comes from DLY04E010 and DLY04E011 in the raw data archive.

* The 500 stations with relatively long series are included in this number.

**There are 2118 stations available for homogeneity test in comparisons from the four categories.

Daily precipitation data in Categories 1, 2, and 4 are stored under file folders ‘DLY04E0n1RSFT’ (a total of 2146 stations), ‘DLY04E0n1’ (a total of 2584 stations), ‘DLY04E1011’ (total 2263 stations), respectively, with corresponding format in ‘format.xls’.

Daily precipitation data in Category 3 can be found under file folders 'DLY04E012RS79y' (total 2145 stations) and 'DLY04E012RSother' (total 1239 stations) with data format in 'format.xls'.

Output files from homogeneity tests on data in Category 1 are stored under file folder 'DLY04E0n1RSFTtest' with detailed subfolder information in Table7.

Table 7. File folders for output files from homogeneity tests on data in Category 1

File folder	Subfolder
DLY04E0n1RSFTtest	output0.0-0.3mm
	output0.0-0.3mmretest
	output0.3-0.4mm
	output0.3-0.4mmretest
	output0.4-0.5mm
	output0.4-0.5mmretest

Output files from homogeneity tests on data in Category 2 are stored under file folder 'DLY04E0n1test' with detailed subfolder information in Table 8.

Table 8. File folders for output files from homogeneity tests on data in Category 2

File folder	Subfolder
DLY04E0n1test	output0.0-0.3mm
	output0.0-0.3mmretest
	output0.3-0.4mm
	output0.3-0.4mmretest
	output0.4-0.5mm
	output0.4-0.5mmretest
	output0.3-0.5mm
	output0.3-0.5mmretest
	output0.5-1.0mm
	output0.5-1.0mmretest
	output1.0-2.0mm
	output1.0-2.0mmretest
	output2.0-3.0mm
	output2.0-3.0mmretest

Output files from homogeneity tests on data in Category 3 are stored under file folder 'DLY04E012RStest' with detailed subfolder information in Table 9.

Table 9. File folders for output files from homogeneity tests on data in Category 3

File folder	Subfile folder
DLY04E012RStest	output0.0-0.3mm
	output0.0-0.3mmretest
	output0.3-0.4mm
	output0.3-0.4mmretest
	output0.4-0.5mm
	output0.4-0.5mmretest
	outputtrace
	outputtraceretest

Output files from homogeneity tests on data in Category 4 are stored under file folder 'DLY04E1011test' with detailed subfolder information in Table 10.

Table 10. File folders for output files from homogeneity tests on data in Category 4

File folder	Sub-file folder
DLY04E1011test	output0.0-0.3mm
	output0.0-0.3mmretest
	output0.3-0.4mm
	output0.3-0.4mmretest
	output0.4-0.5mm
	output0.4-0.5mmretest
	outputtrace
	outputtraceretest
	output0.3-0.5mm
	output0.3-0.5mmretest
	output0.5-1.0mm
	output0.5-1.0mmretest
	output1.0-2.0mm
	output1.0-2.0mmretest
	output2.0-3.0mm
	output2.0-3.0mmretest

9. Homogeneity tests for monthly precipitation series

Before using the RHtests package, monthly precipitation series were log-transformed so that the series could be approximated by a normal distribution, thus applicable to the PMFred algorithm. The test was performed only to monthly precipitation series calculated from the original daily rainfall and snowfall archives, and monthly precipitation series being integrated with the rain gauge related corrections, snow water equivalent conversion and treatments for trace and other flags. Some of the homogeneity test results were presented in 'Report 2011-2012'. Output files from homogeneity tests for treated and original data were stored under file folders 'DLY04E0n1RSFTtest' and 'DLY04E1011test', respectively and subfolders are shown in Table 11.

Table 11. File folders for output files from homogeneity tests on monthly precipitation series

DLY04E0n1RSFTtest	outputpmlylog
	outputpmlylogretest
DLY04E1011test	outputpmlylog
	outputpmlylogretest

10. Verifying changepoints with metadata supports

It should be noted that the results from homogeneity tests were mainly related to undocumented (Type 1) changepoints. However, some changepoints detected by statistical packages may be just artifacts of statistical fitting to the data. It is necessary to verify the changepoints manually, even if the metadata are limited and incomplete. Unfortunately, such verification of the changepoints is very much time-consuming. A comparison was conducted between the changepoints identified for Type 1 only and those after merging Type 0 chanepoints identified with the metadata, for the frequency series of trace precipitation at 500 stations with relatively long records of precipitation data. The numbers of stations with a number of changepoints identified before and after verification with the metadata are shown in Table 12. The temporal distributions of the changepoints before and after verification are shown in Fig. 1. Although the total number of changepoints might not change much, actual changepoints could be pretty different after verification as they might occur at a very different time point than the statistical artifacts. It should be also noticed that the statistical package RHtests 3.0 is very powerful in detecting changepoints as many of the detected changepoints are supported by the metadata.

Table 12. Number of stations with a number of changepoints in the frequency series of trace flags at a station before and after verification with metadata

Number of changepoints	After	0	1	2	3	4	5	6	7	8
Before	Number of stations	44	113	162	90	50	26	7	7	1
0	53	31	11	6	3	2	0	0	0	0
1	114	9	63	29	7	5	1	0	0	0
2	143	3	28	84	22	4	2	0	0	0
3	92	0	9	32	34	10	3	2	2	0
4	59	1	1	9	20	20	6	2	0	0
5	18	0	1	1	2	4	9	0	1	0
6	8	0	0	0	1	1	4	2	0	0
7	8	0	0	1	0	4	0	1	2	0
8	4	0	0	0	1	0	1	0	1	1
9	1	0	0	0	0	0	0	0	1	0

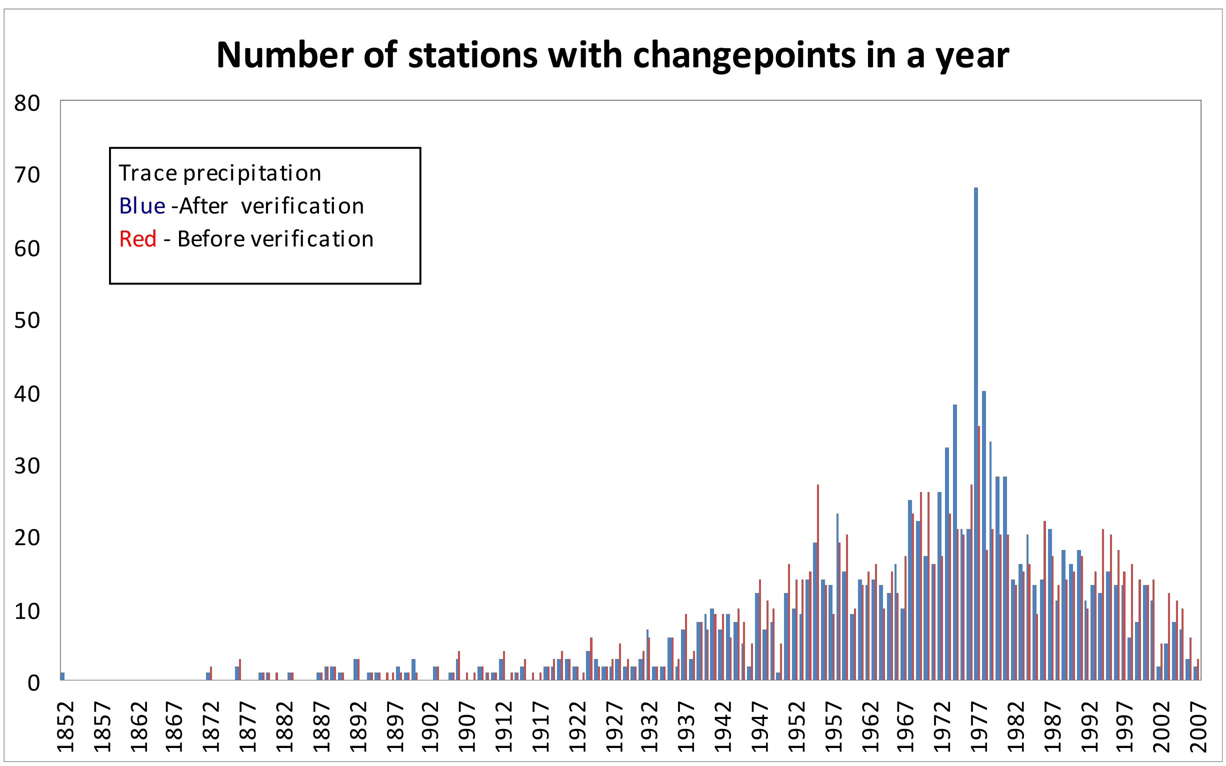

Fig. 1. Temporal distribution of changepoints in the frequency series of trace flags before and after verification with the metadata.

11. Effects of corrections to changepoints

It is also interesting to know the effects of corrections, i.e., converting snowfall to their water equivalents with new SWE factors, rain gauge related corrections, trace and other flags, to changepoints in daily precipitation series. A comparison was shown in Table 13 and Fig. 2, between the changepoints in the frequency series of small amount precipitation (<0.3 mm) detected by the RHtest package from original precipitation data (Category 4) and from data with all applicable corrections applied (Category 1), respectively, for the 500 stations with relatively long data. It was found that homogeneity of the frequency series of precipitation amount smaller than 0.3 mm could be most important for homogenizing daily precipitation series using the quantile-matching adjustment in Wang et al. (2010). Therefore, further work on the homogeneity of the frequency series of small amount precipitation events only focuses on <0.3 mm precipitation. It is not surprising to see that corrections to the original precipitation data might have eliminated some "changepoints" identified from original data while some new changepoints could also have been introduced by the "corrections". In this comparison, all the changepoints were verified with all available metadata for documented changes but there are still many Type 1 changepoints. This comparison further confirms the need of careful examination of changepoints in the dataset.

Table 13. Number of stations with a number of changepoints in the frequency series of small amount precipitation (<0.3 mm) at a station in the original data and data with all applicable corrections

Number of changepoints	Category 1	0	1	2	3	4	5	6	7
Category 4	Number of stations	89	144	130	72	46	9	9	1
0	52	8	11	11	7	12	3	0	0
1	304	66	87	80	43	18	4	5	1
2	101	13	32	25	14	13	1	3	0
3	36	2	11	13	6	2	1	1	0
4	6	0	3	1	1	1	0	0	0
5	1	0	0	0	1	0	0	0	0

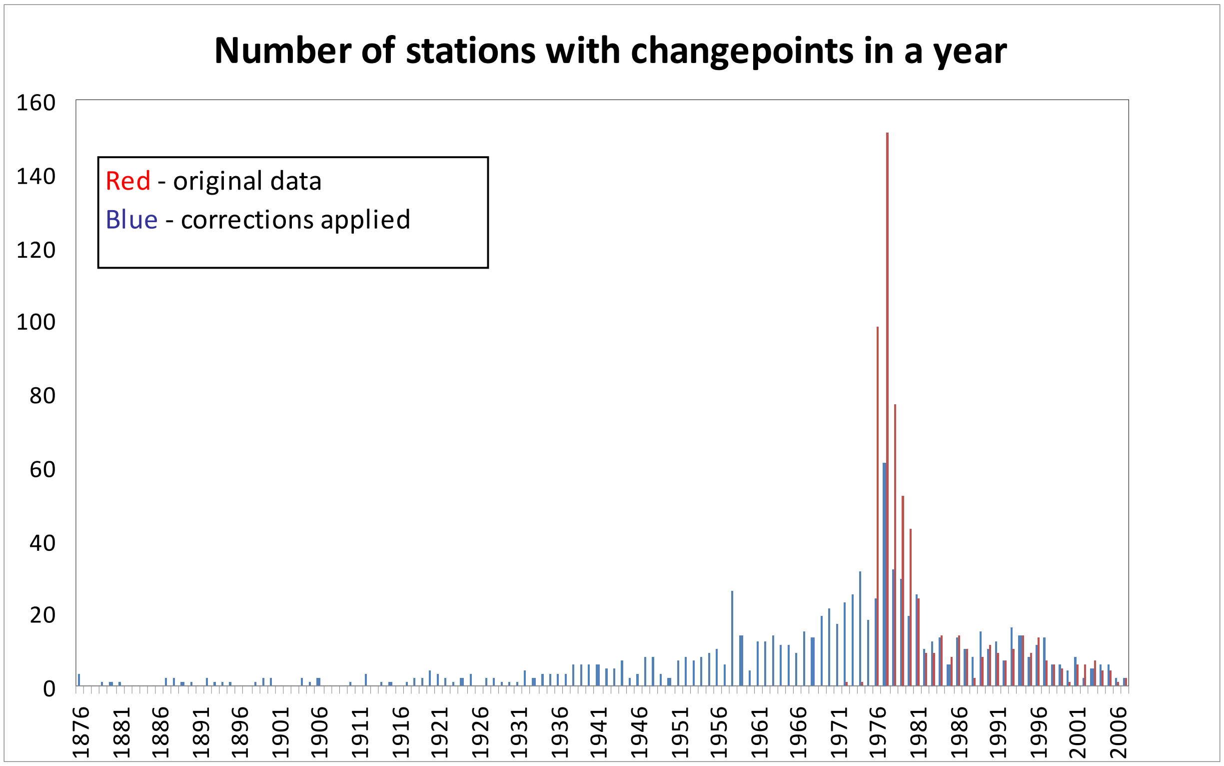

Fig. 2. Temporal distribution of changepoints in the frequency series of small amount precipitation (<0.3 mm) in original data and data with all applicable corrections.

12. Other work

In addition to the work associated to the contract, some other work was done, upon Dr. Xiaolan Wang's request, such as computing mean intensity of daily precipitation, especially reading and processing hourly precipitation data from Hydro Quebec archive.

Mean intensity of daily precipitation for each month (2003-2009) can be found in file folder 'precamount'.

AB Environment data (1986 – 2007) can be found under file folders '1986-2007pcpabenvironment\pcp_1986', …, \pcp_2007' with data format listed in 'format.xls'.

AB Agriculture data (2007 – 2008) are stored under file folders 'abagri2007' and 'abagri2008'.

Manitoba data (2006 -2008) can be found under file folders '2006-2008pcpmanitoba\pcp_2006, \pcp_2007, \pcp_2008' with format described in 'format.xls'.

RMCQ climate day data (2005 – 2008) are stored under file folders '2005-2008pcpRMCQ\pcp_2005climateday, …, \pcp_2008climateday' with output format in 'format.xls'.

Part 3

Data storage and format

All the aforementioned data are stored on an external hard disk provided by Environment Canada. The disk will be delivered to the Scientific Authority or the data can be transferred via Internet. Data format is listed in the enclosed EXCEL file "format.xls".

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Clim_ID	YYYYMMDD	E1011	name	R(0.1mm)	c1R(mm)	cR(mm)	S(0.1mm)	c1S(mm)	cS(mm)	cR+cS(mm)
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1180881	198910 2	0n1	RSFT	0	0.000	0.000	0	0.000	0.000	0.000
1180881	198910 3	0n1	RSFT	0	0.000	0.000	0	0.000	0.000	0.000
1180881	198910 4	0n1	RSFT	50	5.220R	5.220 R	0	0.000	0.000	5.220 R
1180881	198910 5	0n1	RSFT	0	0.000	0.000	0	0.000	0.000	0.000
1180881	198910 6	0n1	RSFT	0	0.000	0.000	0	0.000	0.000	0.000
1180881	198910 7	0n1	RSFT	0T	0.150Q	0.150TQ	0	0.000	0.000	0.150TQ
1180881	198910 8	0n1	RSFT	34	3.590R	3.590 R	0	0.000	0.000	3.590 R
1180881	198910 9	0n1	RSFT	0	0.000	0.000	0	0.000	0.000	0.000
1180881	19891010	0n1	RSFT	10	1.140R	1.140 R	0	0.000	0.000	1.140 R
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1180881	1990 2 7	0n1	RSFT	0	0.000	0.000	0	0.000	0.000	0.000	
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1180881	1990 216	0n1	RSFT	0	0.000	0.000	0	0.000	0.000	0.000	
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1180881	1990 218	0n1	RSFT	0	0.000	0.000	0	0.000	0.000	0.000	
1180881	1990 219	0n1	RSFT	0	0.000	0.000	20	1.920S	1.920 S	1.920	S
1180881	1990 220	0n1	RSFT	0	0.000	0.000	0	0.000	0.000	0.000	
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1180881	1990 223	0n1	RSFT	0	0.000	0.000	0	0.000	0.000	0.000	
1180881	1990 224	0n1	RSFT	0	0.000	0.000	0	0.000	0.000	0.000	
1180881	1990 225	0n1	RSFT	0	0.000	0.000	0	0.000	0.000	0.000	
1180881	1990 226	0n1	RSFT	0	0.000	0.000	0	0.000	0.000	0.000	
1180881	1990 227	0n1	RSFT	0	0.000	0.000	0	0.000	0.000	0.000	
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1180881	1990 3 3	0n1	RSFT	0	0.000	0.000	0	0.000	0.000	0.000	
1180881	1990 3 4	0n1	RSFT	0	0.000	0.000	0	0.000	0.000	0.000	
1180881	1990 3 5	0n1	RSFT	0T	0.150Q	0.150TQ	0T	0.105Q	0.105TQ	0.255TQ	TQ
1180881	1990 3 6	0n1	RSFT	0	0.000	0.000	0	0.000	0.000	0.000	
1180881	1990 3 7	0n1	RSFT	0	0.000	0.000	5	0.480S	0.480 S	0.480	S
1180881	1990 3 8	0n1	RSFT	0	0.000	0.000	0T	0.105Q	0.105TQ	0.105	TQ
1180881	1990 3 9	0n1	RSFT	0	0.000	0.000	18	1.730S	1.730 S	1.730	S
1180881	1990 310	0n1	RSFT	0	0.000	0.000	46	4.420S	4.420 S	4.420	S
1180881	1990 311	0n1	RSFT	0	0.000	0.000	0T	0.105Q	0.105TQ	0.105	TQ
1180881	1990 312	0n1	RSFT	0	0.000	0.000	0	0.000	0.000	0.000	
1180881	1990 313	0n1	RSFT	0	0.000	0.000	48	4.610S	4.610 S	4.610	S
1180881	1990 314	0n1	RSFT	6	0.730R	0.730 R	0	0.000	0.000	0.730 R	
1180881	1990 315	0n1	RSFT	0	0.000	0.000	90	8.650S	8.650 S	8.650	S
1180881	1990 316	0n1	RSFT	0	0.000	0.000	0	0.000	0.000	0.000	
1180881	1990 317	0n1	RSFT	0	0.000	0.000	0	0.000	0.000	0.000	
1180881	1990 318	0n1	RSFT	0	0.000	0.000	0	0.000	0.000	0.000	
1180881	1990 319	0n1	RSFT	0	0.000	0.000	80	7.690S	7.690 S	7.690	S
1180881	1990 320	0n1	RSFT	0	0.000	0.000	18	1.730S	1.730 S	1.730	S
1180881	1990 321	0n1	RSFT	0	0.000	0.000	0	0.000	0.000	0.000	
1180881	1990 322	0n1	RSFT	0	0.000	0.000	0	0.000	0.000	0.000	
1180881	1990 323	0n1	RSFT	0	0.000	0.000	0	0.000	0.000	0.000	
1180881	1990 324	0n1	RSFT	0	0.000	0.000	0	0.000	0.000	0.000	
1180881	1990 325	0n1	RSFT	0	0.000	0.000	0	0.000	0.000	0.000	
1180881	1990 326	0n1	RSFT	0	0.000	0.000	10	0.960S	0.960 S	0.960	S
1180881	1990 327	0n1	RSFT	0	0.000	0.000	0	0.000	0.000	0.000	
1180881	1990 328	0n1	RSFT	0	0.000	0.000	0	0.000	0.000	0.000	
1180881	1990 329	0n1	RSFT	0	0.000	0.000	0	0.000	0.000	0.000	
1180881	1990 330	0n1	RSFT	0	0.000	0.000	0	0.000	0.000	0.000	
1180881	1990 331	0n1	RSFT	12	1.340R	1.340 R	0	0.000	0.000	1.340 R	
1180881	1990 4 1	0n1	RSFT	8	0.940R	0.940 R	0	0.000	0.000	0.940 R	

File folder: e0n1rsftdaily (total 2146 files)

data format(a7,1x,i4,2i2,2x,a3,2x,a4,1x,2(i6,a1,1x,f8.3,a1,1x,f8.3,3a1,1x),f8.3,6a1)

Column 1 Clim_ID

Column2 YYYY

Column 3 MM

Column 4 DD

Column 5 E1011: 0n1 (daily precipitation amount comes fromDLY04E010 and DLY04E011)

Column 6 name: RSFT (Daily precipitation amount comes fromDLY04E010 and DLY04E011. Daily rain gauge related corrections applied, snowfalls converted to water equivalents, and trace and other flags in the data archive treated.)

Column 7 R(0.1mm): original rainfall amount

Column 8: original rainfall flag

Column 9 c1R(mm): corrected rainfall amount with rain gauge related corrections applied OR rainfall trace amount

Column 10: flag 'R' if rain gauge related corrections applied OR flag 'Q' if rainfall trace amount applied

Column 11 cR(mm): rainfall amount with all possible corrections applied including rain-gauge related corrections, trace rainfall amount and corrections for other flags in the data archive.

Column 12: original rainfall flag

Column 13: flag 'R' if rain gauge related corrections applied OR flag 'Q' if rainfall trace amount applied

Column 14: flag 'Y' for rainfall amount corrected for flags other than trace, otherwise blank

Column 15 S(0.1mm): original snowfall amount

Column 16: original snowfall flag

Column 17 c1S(mm): snowfall amount converted to their water equivalents OR snowfall trace amount

Column 18: flag 'S' if snowfall amount converted to their water equivalents OR flag 'Q' if snowfall trace amount applied

Column 19 cS(mm): snowfall amount being converted to water equivalents, with corrections applied for trace and other flags in the data archive.

Column 20: original snowfall flag

Column 21: flag 'S' if snowfall amount converted to their water equivalents OR flag 'Q' if snowfall trace amount applied

Column 22: flag'Y' for snowfall amount corrected for flags other than trace , otherwise blank

Column 23 cR+cS(mm): daily precipitation comes from cR and cS(mm)

Column 24: original rainfall flag

Column 25: flag 'R' if rain gauge related corrections applied OR flag 'Q' if rainfall trace amount applied

Column 26: flag 'Y' for rainfall amount corrected for flags other than trace, otherwise blank

Column 27: original snowfall flag

Column 28: flag 'S' if snowfall amount converted to their water equivalents OR flag 'Q' if snowfall trace amount applied

Column 29: flag'Y' for snowfall amount corrected for flags other than trace , otherwise blank