5A.5 2[ND] GENERATION OF ADJUSTED PRECIPITATION AND HOMOGENIZED TEMPERATURE FOR CANADA: IMPACT OF ADJUSTMENTS AND NEW CHALLENGES

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1. INTRODUCTION

Daily rain and snow; daily maximum and minimum temperatures are available from the National Climate Data Archive of Environment Canada for studying climate change in Canada. However, caution should be used since artificial discontinuities can be sometimes created due to site relocation or changes in instruments and observing practices. A first generation of adjusted precipitation and homogenized temperatures were prepared several years ago for climate trends analysis (Mekis and Hogg 1999; Vincent and Gullett 1999). Since then, issues related to data quality and availability (in particular station closures, relocations and automation) have been identified; and updated station selection and revised methodologies were required to properly address the problems. Annual and seasonal trends were analyzed to determine if the Canadian climate and its extremes had changed over the period of historical observations (Zhang et al. 2000; Bonsal et al. 2001; Zhang et al. 2001, Vincent and Mekis 2006).

This paper provides a brief summary of the issues addressed during the preparation of the 2nd generation of adjusted precipitation and homogenized temperature.

2. ADJUSTED PRECIPITATION

Adjusting rain and snow separately provides opportunities to climate researchers to study the individual elements as well as their relation to each other. Due to the wider availability of the snow ruler data in Canada, only snow ruler measurements (not the Nipher gauge measurements) were included in the process. The total precipitation was computed as the sum of the adjusted rainfall and adjusted snow ruler data. In Canada, when a station is relocated, a new identification number is often given to the new location and the two station's observations can be combined together in order to create longer time series. Procedures based on standardized ratios between tested sites and neighbours and on overlapping observations were applied to adjust the data when necessary (Vincent and Mekis, 2009).

2.1 Station selection

The objective was to include the best quality and/or longest records across the country. The first generation contained precipitation data for 495 locations (Mekis and Hogg, 1999), but since the early 90s, several changes had occurred through the network. First priority was given to the recently finalized and protected Reference Climate Stations (RCS) and locations included in the Global Climate Observing System (GCOS) Surface Network (GSN), but only stations with a minimum of 45 years of observations were retained. As results, the 2nd generation precipitation dataset includes 466 stations (Figure 1).

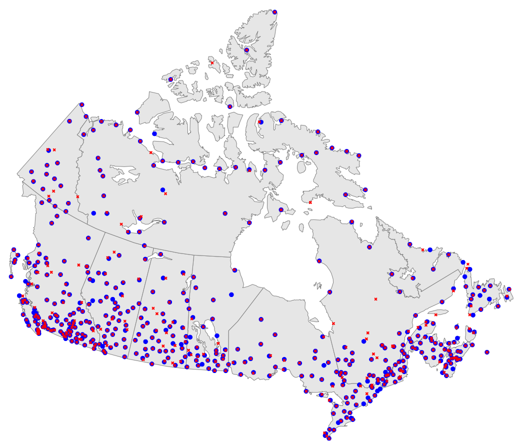

Figure 1. Location of the 495 stations (in red) and of the 466 stations (in blue) for adjusted precipitation.

2.2 Rain-gauge correction

In Canada, the rainfall amount is always underestimated due to wind effects, wetting and evaporation losses. Historical rain observations were typically obtained from MSC rain gauge with the copper or later plastic inside container which was replaced by the Type B rain gauge in the 1970s. More complete description of the gauges with their characteristics is given in Metcalfe et al, 1997. The final adjustment related to MSC copper, plastic and Type B gauges implemented in the 2nd generation dataset and metadata requirements are described in details in Devine and Mekis (2008).

2.3 Snow ruler correction

Knowledge of the water equivalent of the measured freshly fallen snow is of particular importance in water balance and climate related studies. In the climate archive, the precipitation amount (water equivalent) for snowfall events has been determined by assuming a fresh snow density of 100 kg m^{-3}. The snow water equivalent ρ_{swe} map was created based on the comparison of corrected Nipher gauge solid precipitation to snowfall ruler depth measurements at 175 stations with more than 20 years of concurrent observations (Mekis and Hopkinson, 2004; Mekis and Brown, 2010). The Nipher gauge correction involved a careful analysis of station metadata to obtain precise

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information on anemometer heights and the dates when Nipher gauges were activated. The final ρ_{swe} map allows estimates to be obtained for all long-term climate stations in Canada. The spatial pattern is consistent with processes influencing the density of fresh snowfall with values ranging from more than 1.5 over the Maritimes to less than 0.8 over southern-central British Columbia.

2.4 Adjustments for Trace measurements

The measurement of trace precipitation in Canada has changed over time. Not only the definition of trace precipitation (or the lack of definition) was modified, but also the measuring unit (Mekis, 2005). The switch from Imperial to the Metric system, occurring around 1977 – 1978, has decreased the minimum measurable level for rain (snow) from 0.01 (0.1) inch to 0.2 (2) mm. Station relocations and training given to the observers often resulted in a jump in the number of daily trace measurement. For the proper adjustments of the observation frequency, the "Trace Occurrence Ratio" was introduced in the first generation of adjusted precipitation which includes the actual times of observation at each individual location (Mekis and Hogg, 1999) and it is still similarly applied in the 2^{nd} generation dataset.

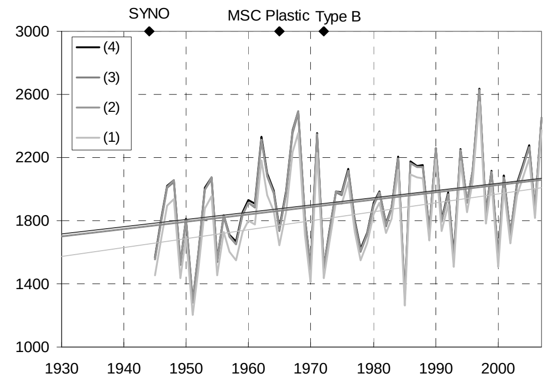
Due to the inconsistencies of trace observations, two versions are provided to the user: stations with all adjustments including trace correction and stations with all adjustment not including the trace adjustment. The frequency of trace observations can be very high on the North, therefore in hydrology related applications it is important to apply the trace adjustments for a better approximation of the atmosphere's water cycle.

2.5 *Impact of the adjustments on precipitation amounts and trends*

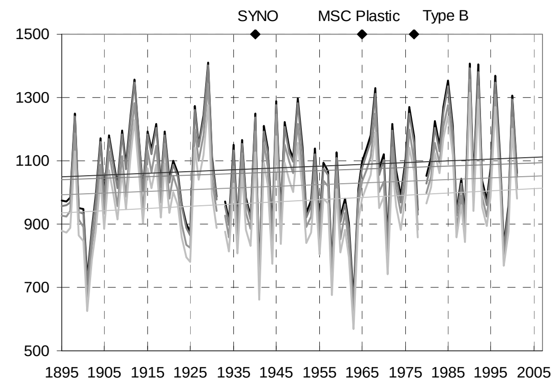
After each correction, the trend [mm/decade] and the relative change of annual total precipitation [%] were computed for comparison purposes. Three locations representing different climate regions were selected to determine the impact of the adjustments on the precipitation amounts (Figure 2a). The coastal station Port Hardy in British Columbia has relatively high annual total precipitation, while the Arctic station Resolute has

(a) Station locations

(b) Port Hardy, British Columbia



(c) London, Ontario



(d) Resolute, Nunavut

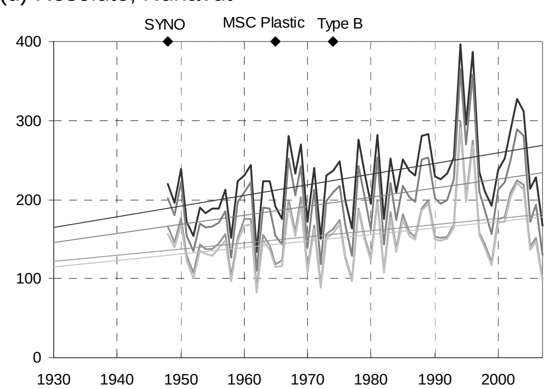


Figure 2. Stepwise corrections at 3 stations representing different climate regions across Canada; (1): original archive data; (2): (1) + rain gauge corrections; (3): (2) + snow density correction and (4): (3) + trace correction.

extremely low annual total precipitation with high frequency of trace events. London in Ontario represents the productive agricultural area within the Great Lakes region.

First, the corrections for the rain gauge instrument were implemented. Overall, the magnitude of this correction was within 5%. Since rain gauge instruments became more accurate in time, the more recent part of the series required less correction compared to the earliest part. As a result, the difference between the trends computed after and before the adjustments is decreasing; this effect is more obvious at locations with high rain amounts (Figure 2b).

Second, correction for the snow water equivalent were applied. Due to the higher snow density ρ_{swe} = 1.4 at Resolute (Figure 2d), more relative adjustment was needed compare to the other two stations: this leads to a higher annual total precipitation amount. Less correction is required for London (Figure 2c) because the snow water equivalent is 1.2. Since the ratio is less than 1 on the West Coast where Port Hardy (Figure 2b) is located, the correction slightly decreased the annual total precipitation amount in this area. The change in trends depend on the actual amount of snow, and since the correction of ruler measurements is consistent through the whole period, in the significance and direction of the trend were not affected very much.

Last, the adjustments for the trace observations were added. Rain trace events on the North are rare so they have relatively small impact on the total precipitation accumulation and the majority of change was due to snow trace events. Most change occurred at Resolute where the trace correction increased the annual total precipitation by about 18% (Figure 2d). Since the trace observation depends on the climate region and it is not consistent through time, the change in magnitude and direction of the trend with the adjustments was not uniform.

The magnitude of all corrections (the ratio of annual precipitation after and before the adjustments) is plotted on Figure 3. The scale on the right of the figure represents the magnitude of corrections required. The correction is largest on the high latitudes where two effects are combined: the effects of snow density correction and the adjustments for the frequent trace observations. On the Canadian Arctic the corrections is relatively high (up to 50%) because the annual total is very low. Overall, the total precipitation was increased almost everywhere in the country as the result of the adjustment procedure, but the required correction is very much depending on the climate region.

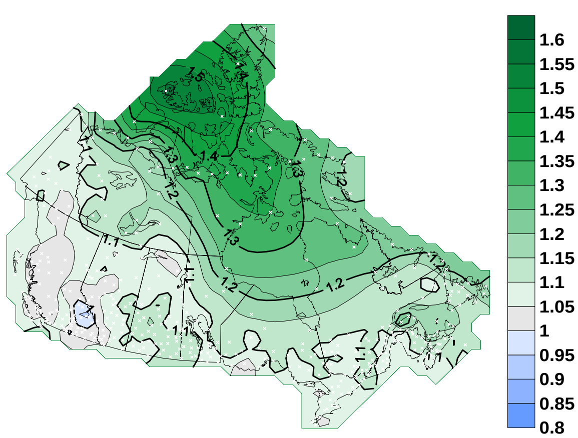


Figure 3. Magnitude of total precipitation correction for the 1950–2008 period.

3. HOMOGENIZED TEMPERATURE

Several years ago, long-term and homogenized temperature dataset were prepared for the analysis of climate trends in Canada (Vincent and Gullett 1999). Non-climatic steps due to instruments relocation and changes in observing procedures were identified using a technique based on regression models (Vincent 1998). Monthly adjustments were derived from the regression models and daily adjustments were obtained from an interpolation procedure using the monthly adjustments (Vincent et al. 2002).

More recently, specific issues have been identified and addressed regarding the Canadian temperature. In particular, a cold bias was detected in the annual and seasonal means of the daily minimum temperature as the result of a change in observing time in July 1961. The magnitude and spatial variability of the bias has been examined and in the 2nd generation dataset adjustments for the bias are based on hourly temperatures. Techniques for detecting and adjusting inhomogeneities in climatological dataset have been also improved. An overview of the new procedures that are used for the preparation of the 2nd generation of homogenized temperatures dataset in Canada is presented.

3.1 Station selection

The original dataset prepared by Vincent and Gullett (1999) contained homogenized temperature for 210 climatological stations across the country. The 2nd generation of homogenized temperature has now 336 stations and it includes most of the 210 stations (Figure 4). Stations were primarily selected based on data quality, length of record and spatial distribution. Further consideration were given to the availability of the precipitation records; however, there are a number of stations with only daily precipitation and not temperature, mostly in the Canadian Arctic. At times, it was necessary to join station observations to produce a long time series for climate change analysis. Consequently, it became essential to verify whether

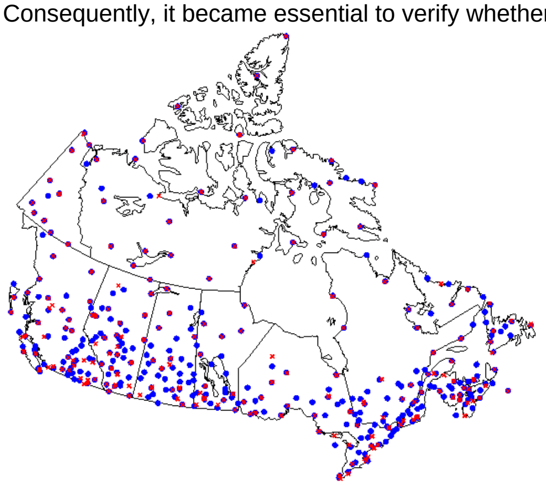


Figure 4. Location of the 210 stations (in red) and of the 336 stations (in blue) for homogenized temperature.

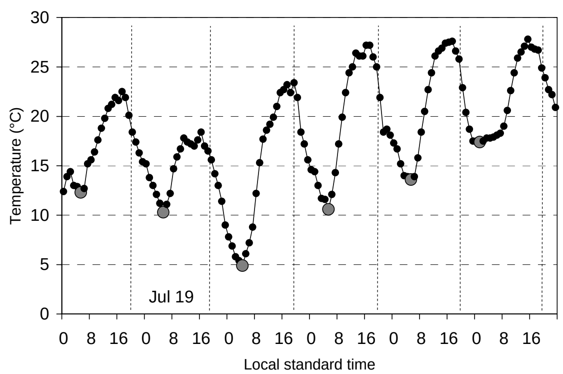
artificial steps have been created at the join of the records.

3.2 Change in observing time - 1961

On July 1961, the climatological day was redefined to end at 0600 UTC at all synoptic stations in Canada. Prior to that date, the climatological day ended at 1200 UTC for maximum temperature and 0000 UTC for the minimum temperature. It was found that this redefinition of the climatological day (change in observing time) has created a cold bias in the annual, seasonal and monthly means of the daily minimum temperature (Vincent et al. 2009).

The current observing time (0600 UTC) is not appropriate for recording the minimum temperature since it is closer to the time at which the actual minimum temperature occurs. Therefore, it is most likely that the same minimum (or a similar minimum) is recorded on two successive days, creating a cold bias. Figure 5 illustrates the problem. The hourly temperatures of Kapuskasing (Ontario) for July 18 to 23, 2007 show the lowest hourly value for both windows. On July 19, the lowest hourly temperature of the window ending at 0000 UTC (1900 LST) and 0600 UTC (0100LST) are different

a) 00 UTC – lowest value



b) 06 UTC – lowest value

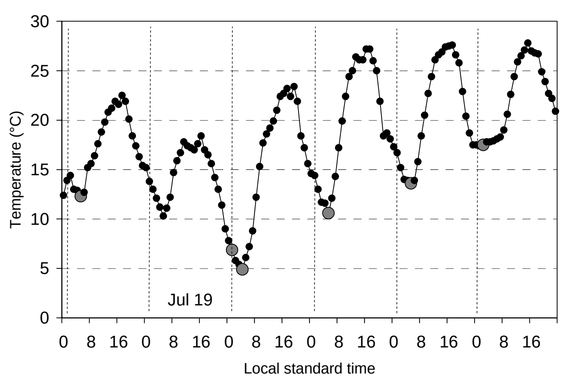


Figure 5. Hourly temperature from 0000 to 2300 LST at Kapuskasing from July 18 to 23 2007. The lowest hourly value is identified by a grey dot for the b) window ending at 00 UTC and d) window ending at 06 UTC.

because 0600 UTC is close to when the actual minimum temperature occurs on the following day.

This has created a bias in the annual, seasonal and monthly means of the daily minimum temperatures which has been further investigated using hourly temperatures taken at 121 stations for 1953-2007 (Vincent et al. 2009). In the 2^{nd} generation of homogenized temperatures, an approach based on hourly temperatures was used to adjust daily minimum temperatures over the period 1961 to today.

3.3 Impact of the adjustments for the change in observing time

Annual and seasonal trends for 1950-2007 were obtained at individual stations before and after adjustments to determine the impact of the adjustments on several climatic parameters based on daily minimum temperature. The annual and seasonal means of the daily minimum temperatures, and the 5^{th} and 95^{th} percentiles were examined. Since many low daily minimum temperatures become warmer during the period 1961-2007, the trends were generally more positive or were reversing from negative to positive with the adjustment, particularly in the eastern regions. The difference between the trends before and after adjustments was positive and the trends have changed by as much as 1°C in numerous locations in the eastern regions.

3.4 Homogeneity assessment

Statistical tests have been recently developed to improve the detection of change points in climatological data time series. The RHtestsV3 package (Wang and Feng 2009) is currently used for the preparation of a 2^{nd} generation of homogenized temperature stations in Canada. The penalized maximal t (PMT) test and the penalized maximal F (PMF) test (Wang et al. 2007; Wang 2008) are applied to detect shifts in the monthly means of the daily maximum and minimum temperatures series. A reference series is also used in conducting the PMT test to detect discontinuities in the difference between a candidate and reference series. The main causes of the discontinuities are retrieved through the station inspection reports when possible. Finally, the Quantile Matching (QM) algorithm (Wang 2009) is applied for adjusting the daily temperatures so that the empirical distributions of all segments of the detrended series match each other.

4. CONCLUSION

Articles regarding the 2^{nd} generation precipitation and temperature datasets are under preparation to provide more details on the applied procedures. Based on the new datasets, trends in Canadian climate will be updated and analyzed. The precipitation and homogenized temperature are available under the Adjusted Historical Canadian Climate Database (AHCCD) web site http://www.cccma.bc.ec.gc.ca/hccd/ .

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