HAS THE ANNUAL POINT SNOWFALL ON THE CANADIAN PRAIRIE INCREASED OR DECREASED?

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ABSTRACT

This study was initiated to determine if the annual Oct 1st through Apr 30th accumulation of daily snowfall at a central location on the Canadian prairie has varied in magnitude over the last 56 years. This requires that the long-term snowfall from 1960-61 through 2015-16 had to be separated from any inherent cyclic variation in the record by averaging these data into 14 four-year periods. The accumulated daily snowfall plus any rainfall was collected and measured as water equivalents in a Nipher-shielded precipitation gauge. The first 16 years of this Nipher precipitation record averaged 15 mm greater than during the following 40 years. During those times when rain fell during the snowfall months, a separate standard rain gauge was activated and its measure also recorded. The differences in recorded water equivalents accumulated in the two gauges constituted the daily snowfall record. The annual snowfall has failed to significantly increase or decrease during the last 40 years, while the daily sum of rain plus snowfall has gained an average of 0.85 mm per year. This implies that the 34 mm increase in combined rain and snow precipitation over the last 40 years resulted from an increase in rainfall during the Oct-Apr period, while the snowfall magnitudes remained constant. (KEYWORDS: climatological station, Nipher-shielded gage (gauge), winter rain, winter precipitation, annual snowfall)

INTRODUCTION

Snow resources on the Northern Great Plains and Canadian Prairies find many uses in economic enterprises: irrigation of crops, power generation, water supplies for domestic and industrial utility, ski slopes and winter recreation, livestock production, inland fisheries, waterfowl nesting, insulation protecting over-wintering crops against low temperatures, and soil water enrichment to grow dryland crops. Snow also possesses environmental importance in snowstorms by hindering vision of highway traffic, as snowdrifts over roads, across feedlots, on railways and in farm yards, and after melting by generating floods. It is a fickle prairie resource in that we receive too much of it in some years and too little in others. Its occurrence and accumulation varies widely both temporally and spatially, presenting challenges in its management, storage, and control. Fortunately, prairie snow falls, accumulates, and melts just before it is needed to grow crops. A study was initiated to determine if the snow falling on the same spot within the Canadian prairie near Swift Current, Saskatchewan has changed in magnitude over the last fifty-six years.

CANADIAN PRAIRIES

That regional snowcover within the 35 million hectares of the Canadian Prairies exhibit large areal variation cannot be overstated. These variations stem from the expansive area across which the region's snowstorms track and the dynamic, wind-swept nature of the region's open environments. The northern Great Plains together with the Canadian prairie are so vast (approaching 1,400,00 km^2) that several separate snowstorms can cross the region at the same time in separate swaths. The wind can blow an area bare of snow and redistribute the snow into deep drifts located only a few meters away. In the process, blinding blizzards may block one's vision and initiate frostbite very quickly. Yearly extremes ranging from snow-free ground to huge snowdrifts characterize the Prairie winters (Figure 1). Consequently, the ease with which representative snowpacks on the plains and prairies can accurately be quantified and their measure extrapolated to larger areas varies widely from location to location and from snowstorm to snowstorm.

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The Northern Great Plains and Canadian Prairies include a loosely defined expanse which forms part of the North American mid-continental plains. These plains slope gradually eastward from the Rocky Mountains to Hudson Bay and the Mississippi River Valley. Landforms within the region are generally subdued, reflecting the effects of massive continental glaciation crossing much of the region during the Holocene Epoch. Topographic relief greater than 80 m is uncommon and usually associated with mountain-borne rivers flowing from west to east, lesser streams from scattered prairie uplands, and existing channels cut by meltwater from long-gone, receding continental glaciers.

Although the region's climate is classed as cool and semiarid, it is well known for its extremes. The weather may range from hot to cold and from very dry to very wet. Winter air temperatures may drop below -40ºC and reach +35ºC during the summer. Mean annual precipitation ranges from 250 to 500 mm with wide fluctuations at all locations within the region. During the summer, potential evaporation greatly exceeds precipitation, owing to considerable solar radiation, warm temperatures, and the ever-characteristic wind. Especially during the winter, the snow-blowing winds contribute to the region's dynamic, climatic nature.

As much as one-third of the annual precipitation can fall as snow, but storms which deposit snow ≥10 cm deep typically occur only two to five times a season (McKay and Gray, 1981). Although usually wide-spread, these storms do not produce uniform snowfalls. They even miss some districts completely, because the fast-tracking, wind-driven storms rarely cover the entire region. High winds, blowing across the subdued, agricultural terrain, are responsible for considerable areal redistribution and sublimation of snowfall and snowcover. Snowpack accumulations also vary in response to an open-sky radiation and energy advection between shifting air masses. Over much of the prairies, these influences may initiate thaw and melt at any time, leading to snowpack losses through evaporation and meltwater releases.

In general, before 1964, ≤ 40% of the Canadian Prairies would retain at least a fraction of their snowcover intact throughout the winter (McKay, 1964) (Figure 2). McKay also reported that snowpacks over many districts in the south-southwest areas of the Prairies frequently disappeared and reformed in response to varying weather and variable winds. East, north, and north-westward of these districts, snowcover disappeared less frequently until at

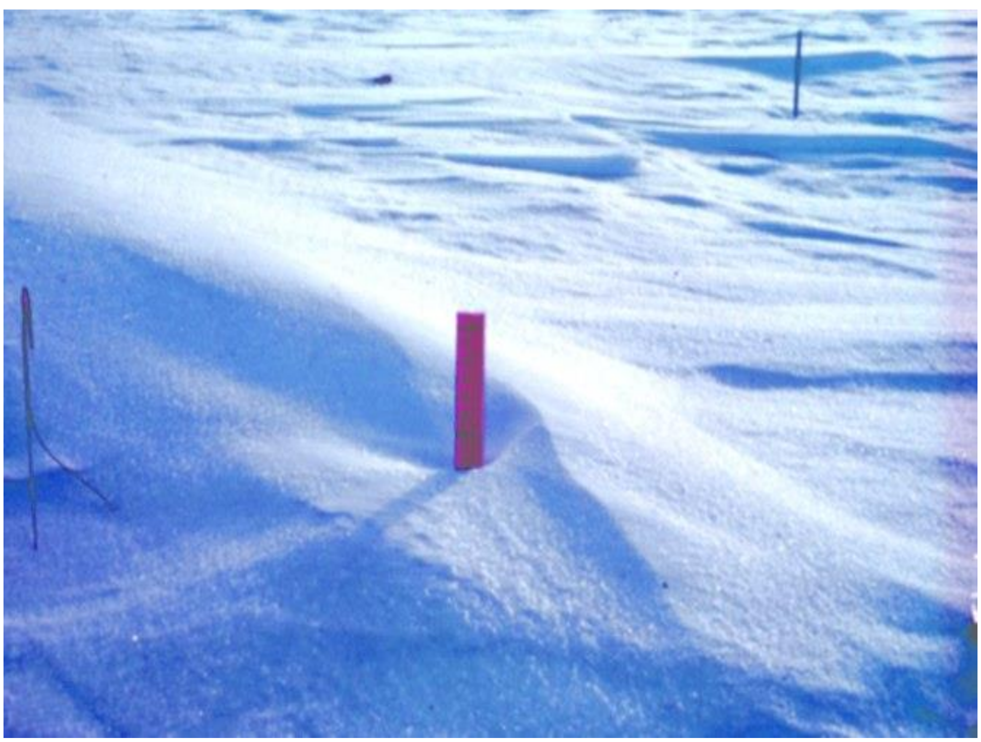

Figure 1. Snowcover across the Canadian Prairies vary widely within short distances both within a weather event and in accumulations from successive events.

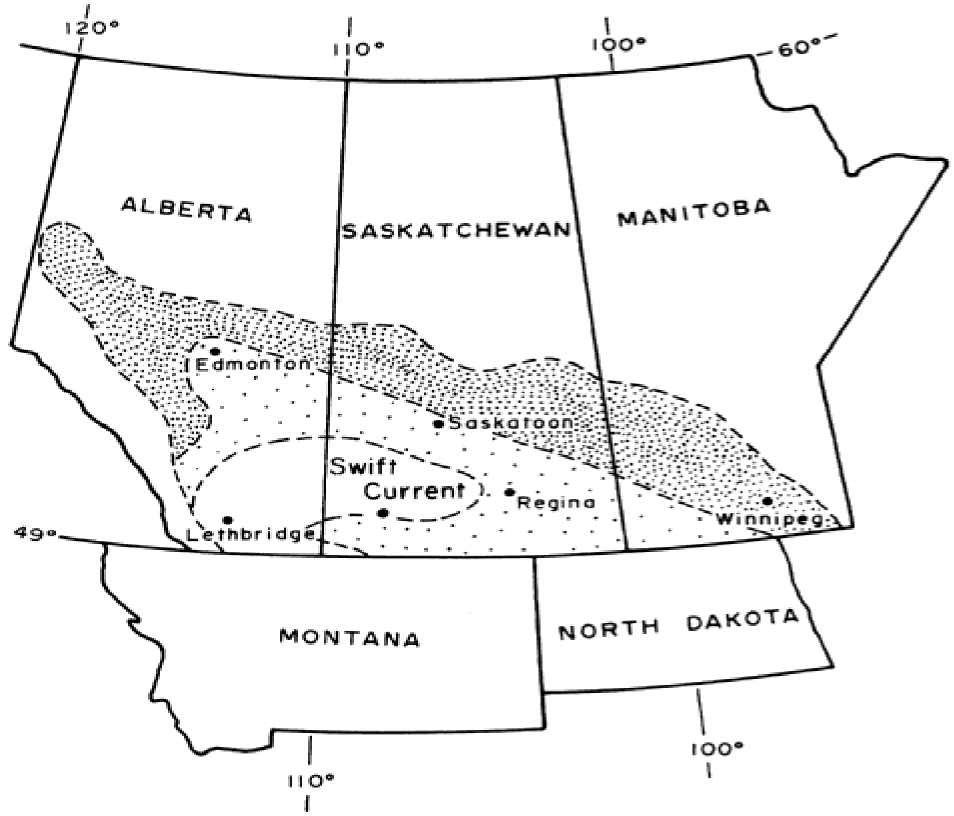

Figure 2. Generalized snowcover permanency during winter over the Canadian Prairies before 1964 (from McKay, 1964); the degree of shading reflected permanency from a zone where snowcover were frequently lost (white) to where they remained throughout the winter (dark).

the region's extremities they tended to persist throughout the winter. If winter air temperatures on the Canadian Prairies have increased since 1964, likely the total area of winter-long snowcover permanency has further decreased. This lack of snowcover winter permanency reflects the dynamic character of the prairie environment.

MEASURING SNOWPACK ON THE CANADIAN PRAIRIES

Reasonable estimates of snowpack depth, liquid water equivalent, and area covered are needed to effectively manage snow resources, but accurate areal estimates are often difficult to obtain. The traditional snow survey using point measures obtained by weighing vertical snowpack cores encounters challenges in sampling. If one assumes that each observation accurately describes the water equivalent covering the immediate one square meter of land, a sample size of ten observations for every 1000 km^2 results in a 1/100,000,000 sample (10 m^2 per 1000 km^2).

The snow water equivalent, WE, at a point, i, expressed as a depth per unit area is commonly computed as the product of the snow depth, d, and the specific gravity (density), f, of a vertically integrated snow column at the point:

$$WE_i = (f)_i \, (d)_i \qquad [1]$$

Snow cores from shallow snowcover found across the wind-swept prairies usually require snowpack coring samplers (tubes) large enough in diameter to obtain an adequate sample for precise measurements of f_i. The standard coring tube used by the Canadian Atmospheric Environment Service, the MSC Sampler, is made from aluminum with a 7.051-cm (inside diameter) cutter (Goodison et al., 1981). The product of snowpack depth, d_i, and point measurements of snowpack density following Equation [1] provides the snow water equivalent at a point ‘i’.

Area Snowcover

The mean areal snow water equivalent, $\underline{WE}$, for any area of interest can be estimated by using a representative number, n, of samples obtained throughout the area:

$$\underline{WE} = \sum_{i=1}^{n} (WE_i) \qquad [2]$$

Unfortunately, in practice, the required n for statistically significance is time-consuming to achieve. The $\underline{WE}$ can also be estimated as the product of the areal mean snowpack depth, $\underline{d}$, and mean specific gravity, $\underline{f}$, obtained from independent statistical surveys of the two snowpack variables following Steppuhn (1975):

$$\underline{WE} = (\underline{f})\,(\underline{d}) + (r\, s_f\, s_d) \qquad [3]$$

where the correlation coefficient, r, between f and d measurements forms an added term together with the sample standard deviations, s, for f and d (including sign). Estimating $\underline{WE}$ by this separation technique following Equation [3] reduces the total sampling effort. The areal variability associated with $\underline{f}$ is much less than it is for $\underline{d}$, reducing the number of labor-intensive snow cores required (Steppuhn, 1976). This leaves more time to sample the more variable d-values, resulting in greater precision in estimating $\underline{WE}$.

Snow Surveys

The variability associated with the accumulation of winter snowcover on the wind-swept Canadian Prairies generally restricts the use of ground snow course surveys in quantifying the annual snow resources within the region. Both spatial and temporal differences in accumulation typically occur, even for snow courses measured side-by-side. Such variability reduces precision and areal representation of the snow depth and water equivalents resulting from the surveys. Wind that often removes snow from one snow course and deposits it onto another tends to confound correlations between measured snowcover accumulations and meltwater runoff.

Precipitation Gauge Measurements

Most water stored in any seasonal snowpack on the plains and prairies originates as snowfall, accumulating over time under winter conditions; any concomitant rainfall usually freezes before infiltrating soils. Consequently, measures of precipitation, especially when occurring as snowfall, have been used to estimate snowpack water equivalent. Equations based on the conservation of mass describe the relationship:

$$WE_t = \sum_{j=1}^{t} (W_j + C_j - E_j - I_j - R_j + B_j) \qquad [4]$$

where the snowpack water equivalent, WE_t, at time t equals the algebraic sum of snowfall water, W, condensation, C, evaporation, E, infiltration into the surface litter or soil, I, runoff, R, and the net mass of deposited or eroded wind-blown snow, B, accumulated by time increments j over the period t beginning on the day that the snowcover begins to accumulate. Measuring the W that falls and seasonally accumulates on a prairie point constitutes the objective of this study.

The Agricultural Climatological Station on the Research Farm near Swift Current, Saskatchewan, forms part of the Federal Atmospheric Environment Service's (AES) Canadian network. This station at 825 m above sea level is located 3 km southeast of the city (50º 16’ N; 107º 44’ W) on a wind-swept plain sloping gently (1% or less) to the north. The year-round station was established at its present location in 1959 and is equipped to facilitate measurements of precipitation, temperatures, radiation at selected wavelengths, hours of sunshine, etc. Further, the precipitation and temperature gauges have remained within the station boundaries since 1959. The Nipher-shielded precipitation gauge (Figure 3), complying with AES site specifications and currently electronically instrumented, is checked manually at 08:00 CST daily, and when necessary at other times. The 131-year mean annual precipitation measured for the Swift Current Station equals 366 mm.

Water equivalents, W, from daily accumulations of snowfall caught in the Nipher gauge serve as point measures of precipitation. Accumulated snowfall and rain over 24 hours, left uncorrected for wind, are melted and summed as daily increments for j over the precipitation accumulation period, t, from October 1st through April 30th of the snowfall year and estimated at the point in water equivalent, WE:

$$WE_j = \sum_{j=1}^{t} (W_j). \qquad [5]$$

Seasonal snowfall precipitation (snowfall plus rainfall) at this Swift Current Station, tallied for this study, covers the last 56 years, 1960-61 through 2015-16, (t = 212 days per year, plus one for leap year). The daily accumulations of rainfall during the accumulation period are measured in a separate standard rain gauge, which is uncovered in anticipation or just as the event begins. Also, sometimes rainfall accumulations can also be physically separated from the snow caught in the Nipher gauge.

Figure 3. A Nipher-shielded precipitation gauge at the Swift Current Agricultural Research Centre farm.

RAIN AND SNOWFALL RESOURCES

Mean annual snowfall plus rain (WE) accumulated in the Swift Current Nipher-shielded gauge during the last 56 years (1960-2016) averaged 115 mm with standard deviation (s) = ±30.3 mm. Working at the same climatological station but analyzing a shorter, 42-year precipitation record, Steppuhn et al. (2003) calculated annual theoretical snowpacks based on the station's snow depth measurements; they identified 1975-76 as the pivotal snow year for separating different snowfall regimes (Figure 4). The longer (by 14 years) record of snowfall water equivalents analyzed in the current study based on actual site rainfall data again indicated a regime change after the 1975-76 snowfall accumulation year (Figure 5). Following visual inspection of the year-to-year variability, the mean annual snowfall WE was again grouped into two successive sub-periods of 16 years (1961-1976) and 40 years (1977-2016) with respective means of 126 mm (s = ±31.5 mm) and 111 mm (s = ±29.1 mm).

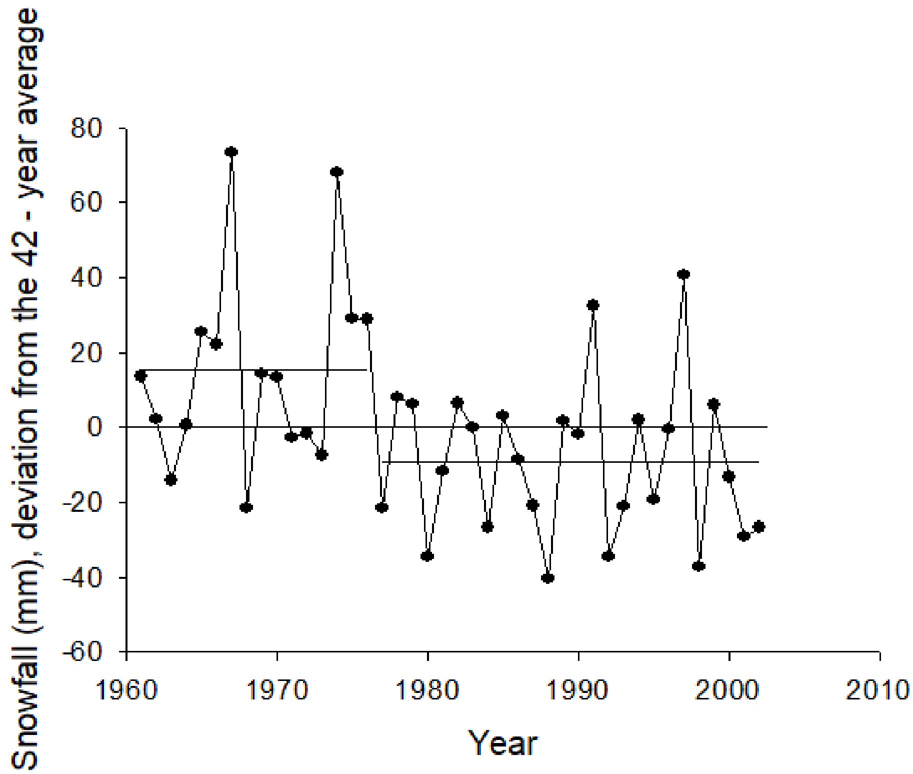

Figure 4. Deviation in the annual Nov 1st through Apr 30th snowfall water equivalent (mm) from the 42-year period means recorded from 1960-61 through 2002-3, near Swift Current, Saskatchewan (taken from Steppuhn et al., 2003).

The calculated mean accumulations for the annual (Oct-Apr) snowfall and the rain plus snowfall Nipher gauge catches are presented for each of ten mini periods of four years each covering the last 40 years. They reveal two different trends for these precipitation measures (Figure 6). Snowfall accumulations appear not to have changed with time ($r^2 = 0.022$), but snowfall plus rainfall tended to increase by an average of 0.85 mm per year during the last 40 years ($r^2 = 0.444$). The rainfall trend as a percentage of the rain plus snowfall catch at the start and at the end of the 40-year snowfall accumulation period equaled 21.1% and 42.0%, respectively (Figure 7). By the end of the 40-year period and in keeping with these trends for rain plus snowfall and for snowfall alone, some 34 mm of rainfall were added to the record (Table 1).

The absolute WE of the snowfall plus rainfall after 40 years has increased to where it now more-or-less equals that of the earlier 16-year period mean, 1960-61 through 1975-76. The annual percent of rainfall in the total precipitation accumulated between Oct 1st and Apr 30th regressed linearly with the number of snow years since 1975-76 revealed a relationship ($r^2 = 0.518$) wherein, on average, it increased 0.517% per year times the number of snowfall accumulation years since 1975-76 plus 20.65% (Figure 7). The percentage increase in snow water equivalent during the snow accumulation season did not occur at the expense of the snowfall magnitude; rather, the rainfall increased.

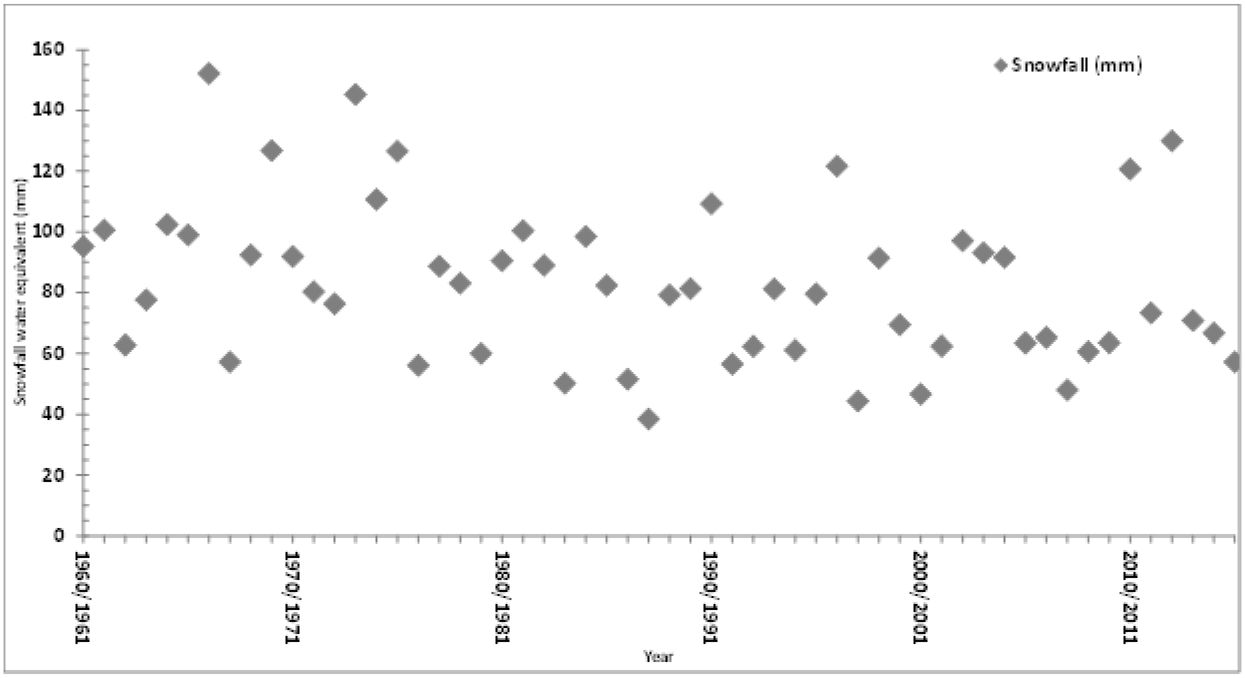

Figure 5. Accumulated Oct 1st -Apr 30th snowfall water equivalent over 56 years, 1960-61 through 2015-16, measured as Nipher-shielded precipitation minus measured rainfall at Swift Current, Saskatchewan.

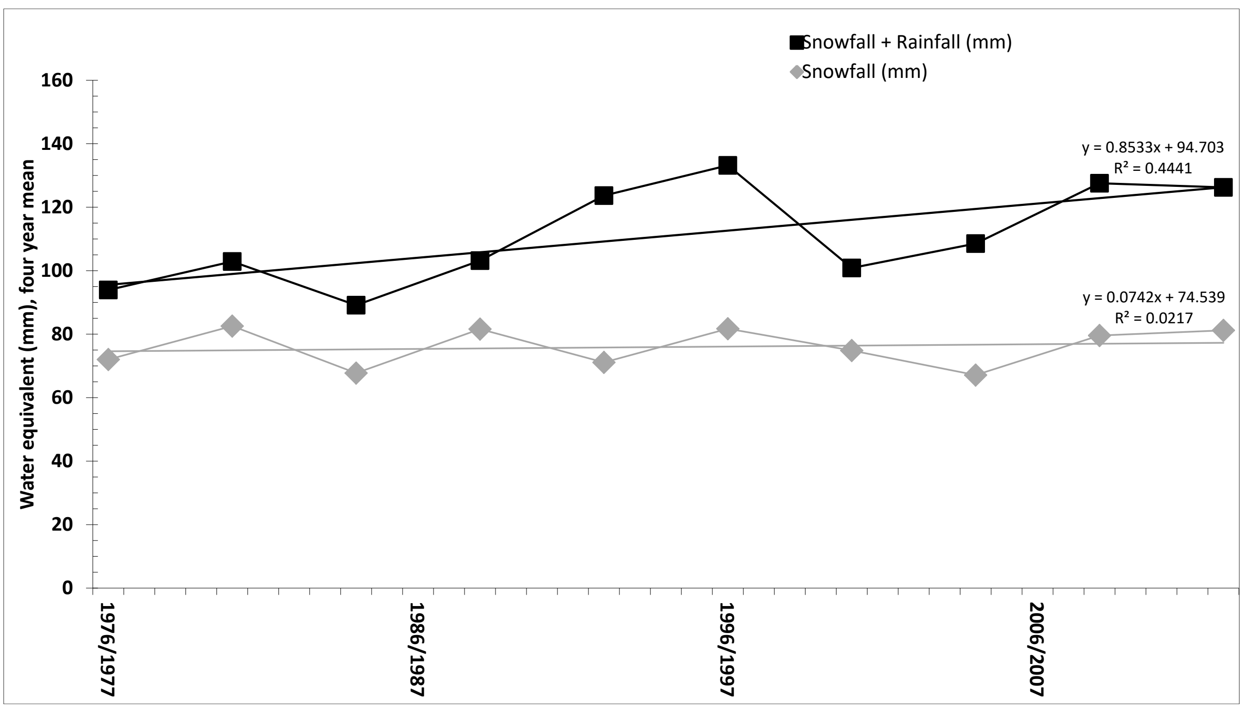

Figure 6. Mean Oct-Apr snowfall and rain plus snowfall accumulated in the Swift Current Nipher-shielded gauge and presented as four-year means covering 40 years, 1976-77 through 2015-16.

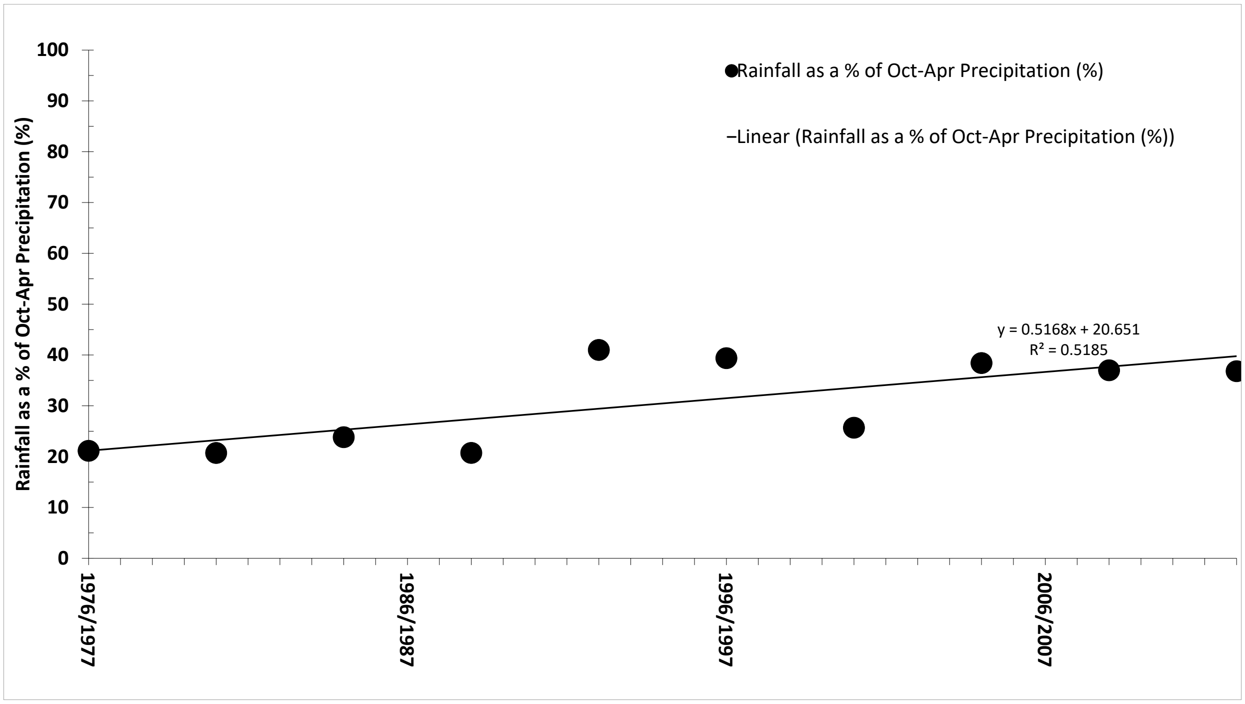

Figure 7. Rainfall as a percentage of Oct-Apr precipitation (rain plus snowfall) plotted as a function of time in years from 1976-77 through 2015-16.

Table 1. Mean precipitation of the cumulated four-year annual rain and snowfall (Oct 1st through Apr 30th) at the start and end of the 40 years covering 1976-77 through 2015-16.

Forty-year Period	Water Equivalent (mm)		
	Snowfall + Rain	Snowfall	Rainfall
Start	94.7	74.7	20.0
End	128.7	74.7	54.0

CONCLUSIONS

In answering the question that generated this study, that is, whether the annual point snowfall on the Canadian Prairies has increased or decreased, the seasonally accumulated precipitation caught in the Nipher-shielded gauge at Swift Current, Saskatchewan was reviewed. This gauge combined rain and snowfall accumulated from Oct 1st through Apr 30th and from which liquid rain water could usually be separated from the ice particles and measured. For pure rain events during the accumulation period, a separate rain gauge also generated an independent rainfall record.

Daily records of rain plus snowfall and of rainfall alone between Oct 1st and Apr 30th were summed in each snowfall season for 56 years. Subtracting daily rainfall from daily precipitation (rain + snowfall) provided daily estimates of snowfall. Two successive sub-periods of 16 and 40 years revealed a 15 mm per year difference, on average, in the mean snowfall water equivalent (WE) between the periods. In the most recent sub-period of 40 years, WE plotted as a function of time in four -year periods showed no significant change in snowfall WE. The trend in the combined rain and snowfall viewed as a function of time (in years) incorporated an average yearly increase of 0.85 mm per year over the last 40 years. Consequently, snowfall WE has not increased or decreased at a central point on the Canadian Prairies during the last 40 years. On average, over the same 40 years, the rainfall has increased.

This increase in absolute snowfall plus rainfall, though not consistent from year-to-year, amounts to 34 mm or about 20% of the seasonal totals from the beginning to the end of the 40 years. A linear regression of rainfall as a percentage of the Oct-Apr Nipher-shielded precipitation with year also confirms an increase in rainfall of approximately 20% over the last 40 years (Figure 7). These trends in annual precipitation, especially for snowfall, occurred within widely variable yearly magnitudes. To subdue the year-to-year variance, long periods of record were required along with analyzing mean precipitation in four-year sub-periods. Consequently, the trends revealed in this study may disappear or change when different periods or period lengths are analyzed.

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