PRECIPITATION ESTIMATION IN CANADA USING ARCHIVAL CLIMATE DATA

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1. INTRODUCTION

Precipitation depends on a myriad of factors and is difficult for Global Climatic Models to estimate reliably (IPPC, 2001). This is likely to remain a problem as available computer resources are likely to be insufficient to reduce the GCM grid size small enough to accurately model clouds and other relevant processes. This paper presents a simple algorithm to estimate precipitation based on its observed dependence on temperature and relative humidity. The method is demonstrated for Canada. Precipitation is estimated for the various seasons and widely different climate regions. Finally, the effect of small temperature and relative humidity perturbations are considered.

2. DATA

This project used data collected at 75 airport stations located throughout Canada as shown in Fig. 1. Hourly measurements of temperature and relative humidity were available while daily precipitation measurements were recorded. The period 1977-2002 was considered as less than 1% of the data was missing for these stations. Observational equipment and procedures also remained relatively constant during this time. In contrast, significant changes occurred in the previous decade including the introduction of the metric system as well as the replacement of the psychrometer by the dewcel. The latter change caused a step discontinuity in relative humidity at very cold temperatures (van Wijngaarden & Vincent, 2005).

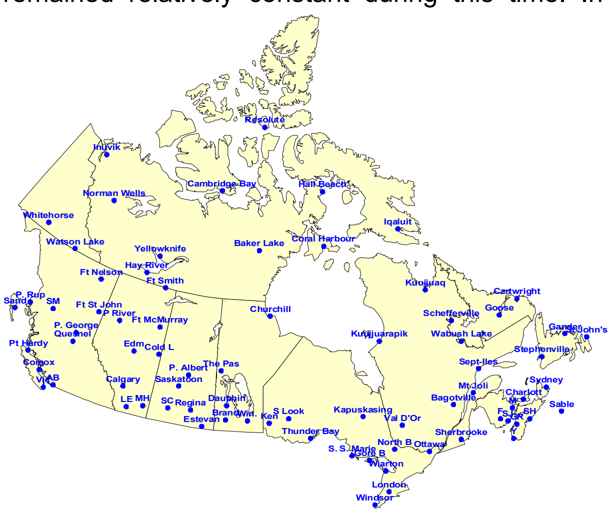

Fig. 1 Stations used in Analysis

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3. DEPENDENCE OF PRECIPITATION ON RELATIVE HUMIDITY AND TEMPERATURE

Precipitation depends strongly on temperature and relative humidity as shown in Fig. 2. Here we used daily observed precipitation and the average daily temperature and relative humidity values were computed from the hourly data. The data was divided into 2 °C temperature and 4% relative humidity intervals. For all seasons, most precipitation falls at higher temperatures when relatively humidity is near 100%. The same pattern is also observed for four regions having very different climates in Fig. 3. The BC Coast contains the 6 stations bordering the Pacific ocean

Table I. Precipitation Distribution for all 75 Stations

Interval (mm)	# Events	% of Total Precipitation
0-1	90703	3.4
1-2	48942	4.8
2-3	30138	5.0
3-4	20365	4.8
4-5	15773	4.8
5-6	12150	4.5
6-7	9894	4.3
7-8	7981	4.1
8-9	6886	3.9
9-10	5686	3.6
10-12	9184	6.8
12-14	6837	6.0
14-16	5195	5.3
16-18	4126	4.7
18-20	3229	4.2
20-25	5573	8.5
25-30	3252	6.1
30-40	3025	7.2
40-60	1753	5.9
60-80	326	1.5
80-100	92	0.6
>100	20	
Totals	291240	100

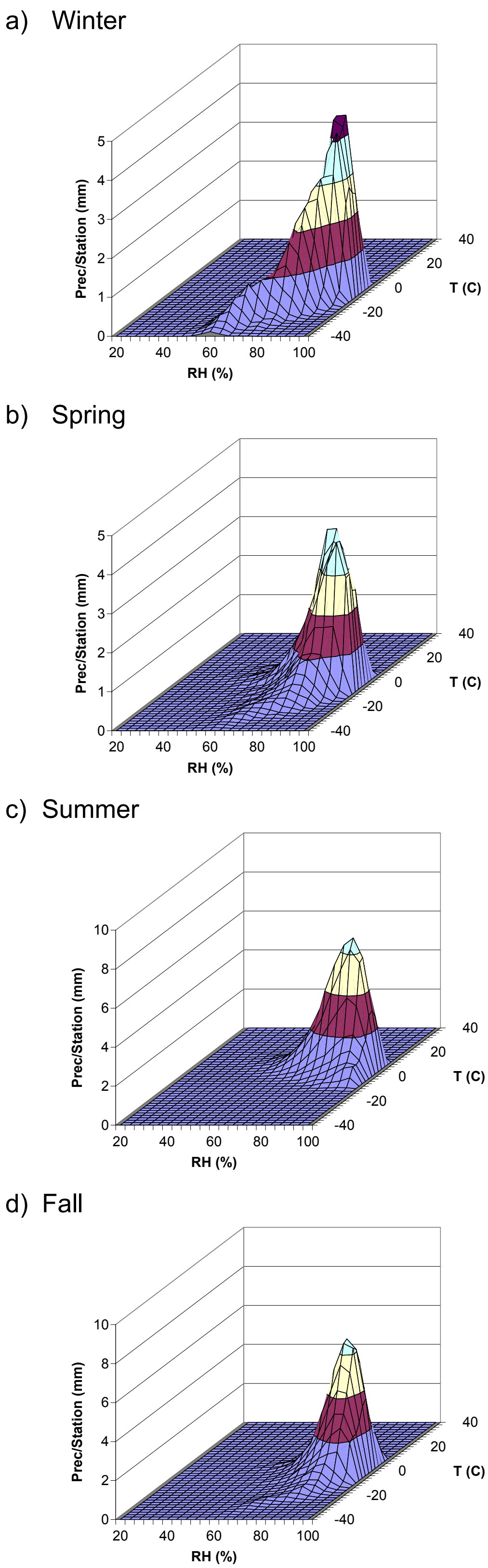

Fig. 2 Seasonal Dependence of Precipitation

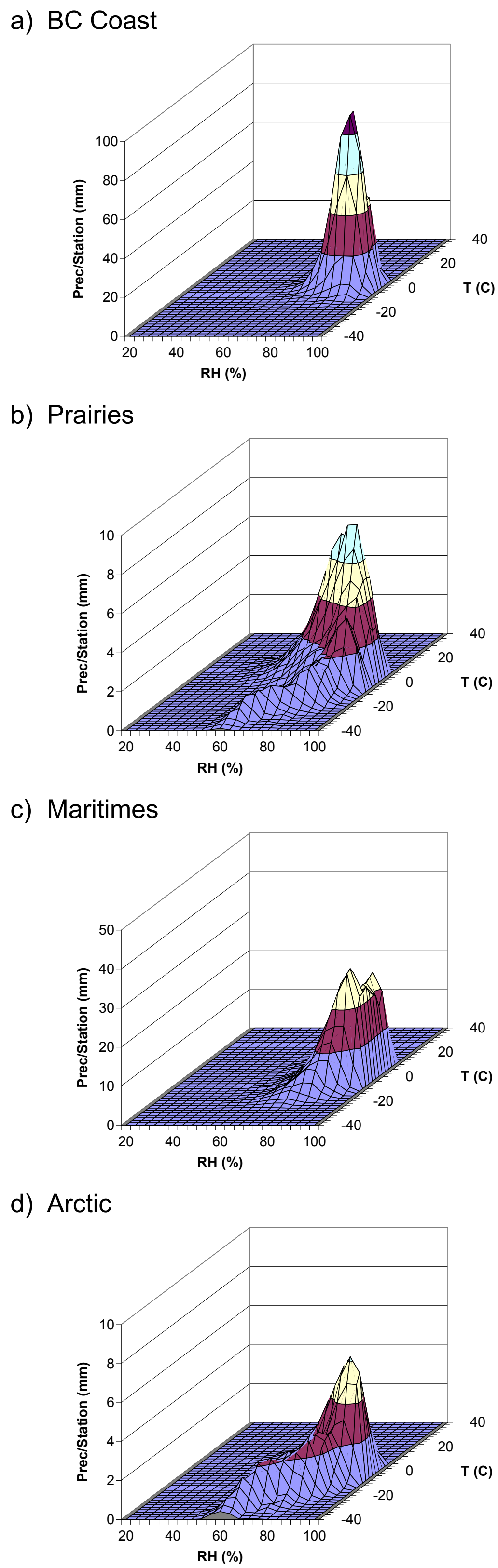

Fig. 3 Regional Dependence of Precipitation

while the Prairies contain 18 stations located in the three Prairie provinces including Forts Nelson and St. John B.C. but excluding Churchill, Manitoba. The Maritimes refers to the 12 stations in the 4 Atlantic provinces excluding Labrador. The Arctic comprises the 13 stations located north of 60^o N latitude as well as Churchill, Manitoba and the two northern Quebec stations Kuujuaq and Kuujarapik.

4. ESTIMATION OF PRECIPITATION

The precipitation distribution is shown in Table I. The observed data was used to compute the precipitation probability $p_i(T, RH)$ as a function of temperature T and relative humidity RH for each of the 21 precipitation intervals. A_i denotes the center of the i^{th} precipitation interval. The precipitation was found by computing

$$P = \Sigma_i A_i \, p_i(T, RH) \qquad (1)$$

The precipitation algorithm was tested as follows. The data observed at all 75 stations and all seasons was randomly divided by a computer into two datasets A and B. First, dataset A was used to determine the precipitation probabilities. Precipitation for dataset B was then estimated. Fig. 4 shows a comparison of the estimated and observed average annual precipitation per station in Canada for the period 1977-2002.

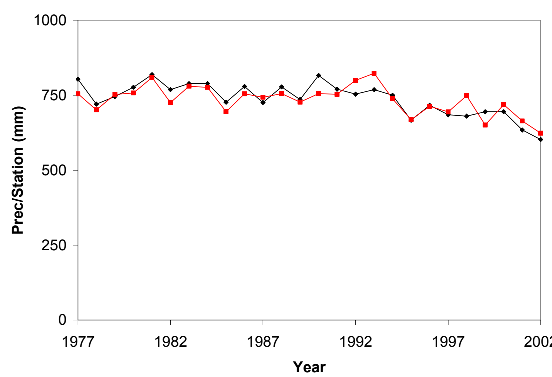

Fig. 4 Validation of Precipitation Estimation Algorithm. The black (red) curve is the observed (estimated) precipitation.

The difference between the observed x_i and estimated y_i annual precipitations are compared by evaluating the root mean square difference

$$R^2 = \Sigma_i (x_i - y_i)^2 / N \qquad (2)$$

where i is summed from 1977 to 2002 and N is the total number of years of data. R can be compared to the standard deviation σ of the observed data about its average value X. For the data displayed in Fig. 4, σ/X =7.6 while R/X = 4.2. A similar result was obtained when the roles of datasets A and B were interchanged ie. dataset B was used to calculate the precipitation probabilities. Hence, the estimated precipitation is considerably closer to the data than the average value. This is not surprising since the estimate accounts for fluctuations in temperature and relative humidity that strongly affect the precipitation. Fig. 4 shows the estimated precipitation agrees quite well with the observed data especially during the 1990s when a severe drought struck much of the Prairies and average precipitation per station decreased in Canada.

The precipitation probabilities computed using data for all stations in Canada in all seasons can be used to estimate precipitation occurring in a single season. The estimated average precipitations per station are less than the observed amount during winter and spring by 22% and 13% respectively but are somewhat higher for summer and fall by 9% and 13% respectively. Similarly, the estimates found using the probabilities computed for all stations in Canada are lower than the observed precipitations for the BC Coast and the Maritimes by 8% and 12% respectively but exceed the observed amounts for the Prairies and the Arctic by 12% and 22% respectively. This is not surprising since factors affecting precipitation vary considerably from season to

Table II Comparison of Observed and Estimated Precipitation. Estimate 1 used precipitation probabilities computed using data observed at all stations in Canada during all seasons. Estimate 2 used precipitation probabilities computed using the listed data set.

Dataset		Observed Precipitation		Est. 1	Est. 2
Region	Season	X (mm)	σ/X (%)	R/X (%)	R/X (%)
Canada	All	737	8	4	
Canada	Winter	167	11	21	12
Canada	Spring	159	11	14	8
Canada	Summer	205	9	11	6
Canada	Fall	205	9	16	7
BC Coast	All	1538	13	12	9
Prairies	All	411	9	17	12
Maritimes	All	1275	10	13	8
Arctic	All	323	7	30	9

season and from one region to another. Considerably improved estimates were found when the precipitation probabilities were computed separately for each season or geographic region as shown in Table II.

5. EFFECT ON PRECIPITATION OF SMALL TEMPERATURE OR RELATIVE HUMIDITY PERTURBATIONS

An interesting application is to study the effect of a small change in temperature or relative humidity. Table III shows a 1% decrease in relative humidity while temperature remains unchanged, decreases precipitation by about 6% in all seasons and in all regions of Canada. The effect of a 1 ^{o}C temperature increase while relative humidity is unchanged, increases the precipitation in each season. The effect varies considerably from one region to another. The change in precipitation is much less in coastal areas such as the BC Coast and the Maritimes. The reason for this is evident in Table IV which shows that these two regions receive significantly more of their annual precipitation during winter, the coldest season rather than in summer. The opposite is true for the Prairies and the Arctic.

In practice climate change is likely to generate changes in both temperature and relative humidity that exert opposite effects on precipitation as shown by Table III. For Western Canada and the Arctic, temperatures during the winter and spring seasons have increased by about 2 ^{o}C during the last century (Zhang et al, 2000). It also appears that the same geographical region has experienced a relative humidity decrease of several percent in spring and possibly winter during the last 50 years (van Wijngaarden and Vincent, 2004). Interestingly, there has been a substantial reduction in winter precipitation affecting the Western Canada during this period (van Wijngaarden & Vincent, 2004 and Mekis & Vincent, 2005).

Table III Change of Precipitation due to 1 ^{o}C Temperature Increase and a 1% Relative Humidity (RH) Decrease

Dataset		% Change in Precipitation	
Region	Season	1^{o}C Increase	1% RH Decrease
Canada	All	+3.9	-6.7
Canada	Winter	+7.2	-5.5
Canada	Spring	+4.6	-6.5
Canada	Summer	+3.9	-7.3
Canada	Fall	+5.1	-7.5
BC Coast	All	+1.3	-6.7
Prairies	All	+6.1	-7.4
Maritimes	All	-1.1	-7.1
Arctic	All	+7.3	-6.1

Table IV: Percentage of Total Precipitation received in each Season during 1977-2002

Region	Winter	Spring	Summer	Fall
Canada	23	22	28	28
BC Coast	35	20	12	33
Prairies	11	22	47	21
Maritimes	27	24	22	27
Arctic	14	16	40	31

6. CONCLUSIONS

Precipitation can be estimated using records of temperature and relative humidity measurements. This empirical approach requires much less computational resources than complex models. It successfully estimates precipitation for various seasons and different climate regions. It also enables the study of how precipitation is affected by small perturbations of temperature and relative humidity that could be caused by climate change.

Future work could include data from additional stations. Hourly precipitation measurements would be ideal. It would be desirable to have sufficient data to compute the dependence of precipitation probability not just on temperature and relative humidity but also on other factors such as changes in hourly surface pressure that indicate oncoming frontal systems.

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