Examination of discontinuities in hourly surface relative humidity in Canada during 1953–2003

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[1] Hourly values of relative humidity recorded at 75 stations across Canada were examined. Data were checked for possible discontinuities arising because of changes in procedures and instruments. It was found that the replacement of the psychrometer by the dewcel has produced a decreasing step in relative humidity at a number of stations. The historical records were closely examined to retrieve the dewcel installation date, and a procedure based on regression models was applied to determine if it corresponds to a significant step. Results show that there are more stations experiencing a dewcel step in the winter than in the summer. Examination of the trends also reveals that the step often accentuates the decreasing trends originally observed during winter and spring. However, significant steps taken into account, it appears that the relative humidity still decreased by several percent in the spring during 1953–2003 in western Canada. It seems that the southern and coastal stations are not as much affected by this change of instruments.

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1. Introduction

[2] Relative humidity is an important climatic indicator as it directly affects atmospheric visibility, strongly influencing the formation of clouds, fog and smog [*Elliott and Angell*, 1997; *Teixeira*, 2001]. Indeed, it is commonly used in conjunction with temperature measurements to determine the dew point temperature that in turn permits an estimate of cloud height. This is critical for aviation and hourly measurements of relative humidity along with temperature and dew point have been commonly made at many airports for years. These records can also offer an opportunity to test for evidence of climate change [*Intergovernmental Panel on Climate Change*, 2001; *Sturm et al.*, 2003].

[3] It is well known that changes in instruments, observers, and observing procedures can introduce artificial discontinuities into climate time series. These discontinuities can affect the proper assessment of climate trends and interfere with the identification of any real climate change. In Canada, careful examinations of temperature and precipitation measurements have been made. For temperature, changes in instrument exposure and in observing time were often the prime source of artificial steps [*Vincent and Gullett*, 1999]. Regression models have been used to identify these steps and to produce adjustment factors in an attempt to determine better estimates of the temperature trends [*Vincent et al.*, 2002]. For precipitation, data have been affected by changes in measurement procedure as well as the use of various gauge types. Each gauge has its own characteristic wetting loss and response to the wind [*Metcalfe et al.*, 1997]. Hence adjustments to the measured rain and snow observations must be made [*Mekis and Hogg*, 1999]. Concerns have been expressed regarding the reliability of relative humidity observations. Psychrometers yield anomalously high values of relative humidity at low temperatures when the wet bulb is coated by ice (K. Devine and B. Sheppard, Meteorological Service of Canada, Toronto, Ontario, Canada, personal communication, 2004, hereinafter referred to as Devine and Sheppard, personal communication, 2004). Similarly, other studies have found that dewcels housed in a sheltered Stevenson screen are less sensitive to icing than other relative humidity sensors and exhibit lower values of relative humidity at very cold temperatures [*Déry and Steiglitz*, 2002; *Anderson*, 1994; *Makkonen*, 1996].

[4] The purpose of this work is to examine the relative humidity for potential discontinuities due to known changes in instruments and observing procedures and to assess the impact on seasonal trends during the period 1953–2003 in Canada. This study has undertaken one of the first analyses of hourly data recorded at 75 airport stations. Data taken near the urban centers of Toronto, Vancouver, and Montreal whose metropolitan areas have greatly grown over the last

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decades possibly creating large urban heat islands and influencing the detection of any climate trends, was excluded.

2. Background

[5] Relative humidity was determined in the 1950s and 1960s using a psychrometer consisting of a wet and dry bulb thermometer. The dew point was first obtained using a table (psychrometric tables, Department of Transport Canada Meteorological Division, 1 July 1953) that plotted the temperature depression (dry bulb minus wet bulb temperature) versus the wet bulb temperature. Next, the relative humidity was determined using a second table that plotted the dew point temperature versus the dry bulb temperature. These tables also took into account the station height as well as whether the psychrometer was ventilated. The temperature depression increment ranged from 1°F for temperatures above 55°F to 0.1°F for temperatures below 10°F. The resolutions of the dew point temperature and relative humidity were 1°F and 1%, respectively.

[6] Refined psychrometric tables (ventilated psychrometer (station elevation <1000, 1000–2500, >2500 feet) and nonventilated psychrometer (station elevation <1000, 1000–2500, >2500 feet), Department of Transport Canada Meteorological Division, 1959) that listed the temperature depression in smaller increments came into use in the 1960s. Both the relative humidity and dew point temperature were determined by a single table that plotted these quantities as a function of the temperature depression and the dry bulb temperature. The resolutions of the dew point temperature and relative humidity remained unchanged.

[7] Psychrometers were replaced by the dewcel beginning in the early 1970s at most airport stations [*Atmospheric Environment Service Canada*, 1976]. This instrument senses the change in conductivity of lithium chloride when it absorbs water from the surrounding air. Atmospheric Environment Service Canada standards require dewcels to be calibrated at −25°C, 0°C and 20°C for relative humidity ranging between 11 and 100% (D. Sutherland, Stevens Analytical, Montreal, Quebec, Canada, personal communication, 2003). A computer program calculates the dew point temperature and relative humidity from the measured dewcel conductivity and ambient air temperature and there is no need to use any tables to obtain the relative humidity.

[8] A change from the imperial to the metric system was applied to the National Digital Climate Archive in Canada in 1977. Prior to that date, wet bulb and dry bulb temperatures at airport stations were measured with a resolution of 0.1°F although the archive only recorded those temperatures with a resolution of only 1°F. These temperatures were later converted to Celsius and are now available with a resolution of 0.1°C in the digital archive. The conversion to the metric system did not affect the resolution of the observed relative humidity data stored in the archive which is recorded with a 1% resolution.

3. Data

[9] Hourly observations of climate data for the period 1953–2003 were retrieved from the National Climate Data and Information Archive of the Meteorological Service of Canada, Environment Canada. The database contains climate observations from several hundred stations across the country, with some data starting as early as the end of the 1890s. Hourly observations first began at airports in the late 1940s and early 1950s. These observations have been accumulated in digital form only from the year 1953. These climate stations were operated by a variety of organizations including the Canadian Defence Department, the Meteorological Service of Canada and volunteer observers. Some stations, primarily in the Arctic, only became operational in the late 1950s.

[10] In this study, a station was included if it has operated for a minimum of 40 years during the period 1953–2003. In addition, the data record was checked to ensure that less than 1% of the data was missing. A typical station had only a few hundred missing hourly values over a 50 year period. This criterion was relaxed for Arctic stations where typically 5% of the data was missing. As a result, 75 stations located throughout Canada were chosen for this analysis.

[11] Relative humidity varies considerably during the day and from season to season. In addition, the daily range of relative humidity is strongly affected by the geographic location of the station. For a relatively dry region such as the Canadian prairies, relative humidity in the summer can change from 40% in the afternoon to over 80% at night. Smaller daily variation in relative humidity occurs at stations located along the Pacific and Atlantic coasts where typical readings can vary between 70% during the day and 90% at night. Indeed, readings of 100% relative humidity are not uncommon at these stations. Maximum relative humidity typically occurs in the summer for Arctic stations when ice melts and water is readily available. In contrast, southern stations usually have their minimum relative humidity values in the summers which can be hot and dry.

4. Effects of Known Changes in Procedure and Instrumentation

[12] Relative humidity observations were closely examined in order to determine if the changes in tables in the 1960s and the replacement of the psychrometer by the dewcel in the early 1970s have created any changes in the data behavior that could affect the estimation of the trends over 1953–2003. Histograms were produced for each decade using all hourly observations from the 75 stations (Figure 1). The observations were sorted into intervals of 1% and the frequency of observations was calculated for each season. The histogram for the 1953–1962 period shows distinctly higher frequencies occurring at fixed relative humidity values, such at 100%, 96% and 93%. This problem continues in the 1963–1972 period but to a much lesser extent. The reason for this is that the psychrometric tables used until the 1960s had larger increments for the wet/dry bulb temperatures and certain relative humidity values appear more frequently than other values. The shape of the histograms appearing for the periods 1953–1962 and 1963–1972 are similar. Hence it was concluded that the change in resolution of the psychrometric tables did not have a major impact on relative humidity trends.

[13] Figure 1 also shows a substantial increase in the frequency of relative humidity occurring near 60% mostly in winter starting from the 1973–1982 period. The histo-

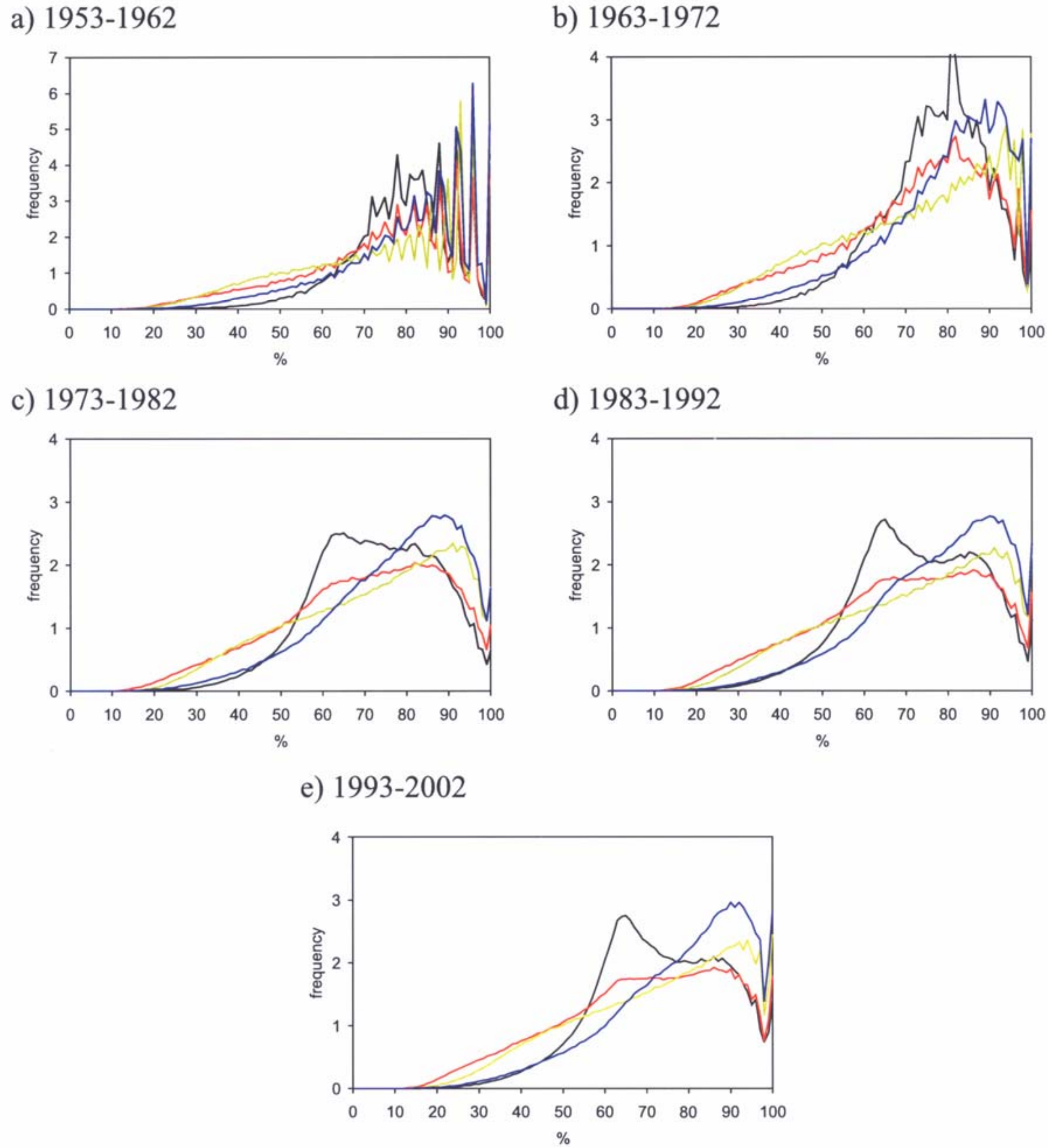

Figure 1. Relative humidity histogram for all 75 stations (winter, black; spring, red; summer, green; and fall, blue). The frequency is plotted along the vertical axis versus the relative humidity. Each curve is normalized to unity, which equals the sum of observing all possible relative humidity.

grams for spring, summer and fall show much less change. This could be associated with a change in climate but it suspiciously corresponds to the introduction of the dewcel in the 1970s. Some studies have expressed concerns regarding the reliability of the relative humidity observations at very cold temperatures. Psychrometers are likely to produce high values of relative humidity at low temperatures when the wet bulb thermometer is coated with ice (Devine and Sheppard, personal communication, 2004), while dewcels observations are lower since the instruments are sheltered [*Déry and Steiglitz*, 2002]. These high frequencies of relative humidity near 60% occur in the coldest season and remain in the subsequent decades.

[14] The seasonal time series of the relative humidity at individual stations were also visually inspected. A decreasing step was identified mostly in the early 1970s during the

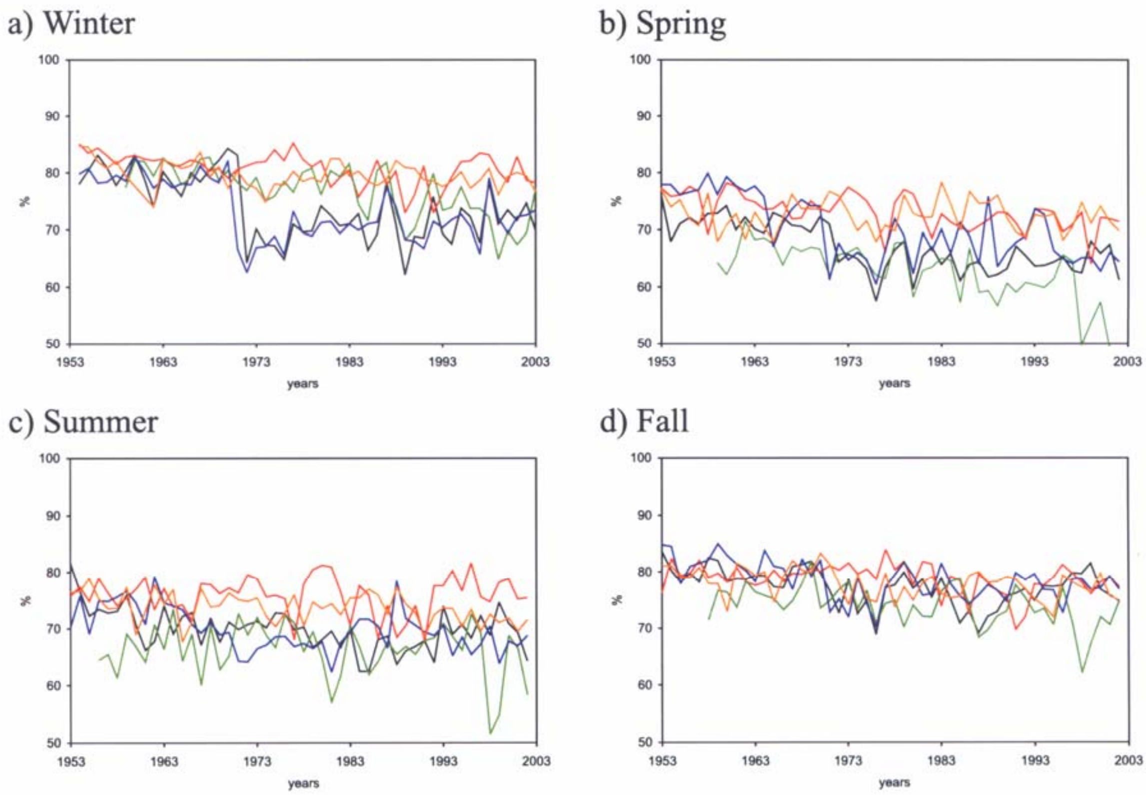

Figure 2. Seasonal relative humidity time series over 1953–2003. Dates of dewcel installation are as follows: 1971, The Pas (black); 1975, Wiarton (red); 1993, Peace River (green); and 1970, Hay River (blue). A dewcel has never been used at Greenwood (orange).

winter at several sites. This step appears to coincide with the replacement of the psychrometer by the dewcel. Figure 2 shows the seasonal time series for five stations. For The Pas and Hay River, a decreasing step is clearly visible at the dewcel installation date in the winter but is not as obvious in the other seasons. This decreasing step can artificially accentuate the decreasing trend in the time series and erroneous assessment of the overall trend can be made if the step has not been considered.

5. Methodology

[15] The historical records of the 75 stations were closely examined to retrieve the dewcel installation dates. This was not possible for some stations as their documented history is incomplete. Exact or approximate dates were found for 58 stations, and they are listed in Table 1. Figure 3 shows that most dewcels were installed in 1971 and 1972. For the remaining stations, records of dewcel maintenance were found for 14 stations although the installation dates were not recorded, while the dewcel has not been used for three stations (the psychrometer is still being used today).

[16] A procedure based on regression models was used to determine if a statistically significant step exists at the installation date. This procedure also allows the estimation of the trend when a step is either taken into consideration or not.

[17] Model 1 was first applied to the seasonal time series of each individual station:

$$y_i = a_1 + b_1 t_i + e_i. \tag{1}$$

Here y_i is the seasonal relative humidity for year t_i, and e_i is the residual. The estimate of the slope is given by b_1. The residuals can be examined to determine if the model is adequate to describe the data. In particular, model 1 can be rejected if the first lag autocorrelation in the residuals is statistically significant [*Vincent*, 1998].

[18] A second model was applied to the seasonal time series in order to describe a potential step at the installation date. Model 2 is given as

$$y_i = a_2 + b_2 t_i + c_2 I + e_i. \tag{2}$$

The estimate of the slope before and after the step is given by b_2 which assumed that the same trend continues after the step. The variable I is an indicator variable which takes the value zero and one, before and after the dewcel installation date, respectively. The magnitude of the step is given by the parameter c_2. This model has been proposed for the detection of change point in climatological time series [*Wang*, 2003] but here it is written using a different form [*Neter et al.*, 1985].

Table 1. Stations Considered in This Study

Station Name	Observation Period[a]	Dewcel Installation Date
	British Columbia	
Abbotsford A		31 Mar 1971
Comox A		1970[b]
Fort Nelson A		23 Oct 1980
Fort St John A		31 Aug 1972
Port Hardy A		25 Aug 1972
Prince George A		Jun 1971
Prince Rupert A	1961–2003	1972[b]
Quesnel A		27 Oct 1983
Sandspit A		8 Dec 1971
Smithers A		2 Jun 1971
Victoria Int A		uncertain
	Yukon	
Watson Lake A		uncertain
Whitehorse A		29 Mar 1972
	Northwest Territories	
Fort Smith A		uncertain
Hay River A		8 Dec 1970
Inuvik A	1958–2003	14 Sep 1974
Norman Wells A		1 Sep 1973
Yellowknife A		1969[b]
	Nunavut	
Baker Lake A		6 Oct 1971
Coral Harbour A		16 Oct 1971
Cambridge Bay A		22 Aug 1990
Hall Beach A	1956–2003	14 Aug 1987
Iqaluit A		uncertain
Resolute A		1971[b]
	Alberta	
Calgary Int A		1971[b]
Cold Lake A	1954–2003	1 Dec 1971
Edmonton Int A	1961–2003	1970[b]
Fort McMurray A		1 Jun 1982
Lethbridge A		27 Jul 1979
Medicine Hat A		27 Jul 1970
Peace River A	1955–2003	8 Aug 1993
	Saskatchewan	
Estevan A		20 Nov 1990
Prince Albert A		uncertain
Regina A		17 Aug 1970
Saskatoon A		15 Aug 1970
Swift Current A		1 Oct 1970
	Manitoba	
Brandon A	1958–2003	1969[b]
Dauphin A		16 Nov 1971
The Pas A		8 Jul 1971
Churchill A		uncertain
Winnipeg Int A		Nov 1972
	Ontario	
Gore Bay A		uncertain
Kapuskasing A		uncertain
Kenora A		15 Jan 1970
London A		1970[b]
North Bay A		15 June 1970
Ottawa Int		1970[b]
Sault Ste Marie	1961–2003	13 Aug 1970
Sioux Lookout A		10 May 1980
Thunder Bay A		3 Nov 1970
Wiarton A		3 Dec 1975
Windsor A		24 Nov 1971
	Quebec	
Bagotville A		No Dewcel
Kuujjuaq A		20 Jun 1978
Kuujjuarapik A	1957–2003	uncertain
Mont Joli A		22 Aug 1968
Schefferville A		1971[b]
Sept-Iles A		uncertain
Sherbrooke A	1962–2003	20 Aug 1971
Val-D'Or A	1955–2003	25 Aug 1970
	New Brunswick	
Fredericton A		20 Sep 1969
Moncton A		28 Nov 1973
Saint John A		1970[b]
	Nova Scotia	
Greenwood A		No Dewcel
Sable Island		uncertain
Shearwater A		No Dewcel
Sydney A		3 Jun 1972
Yarmouth A		28 Feb 1972
	Prince Edward Island	
Charlottetown A		Apr 1970
	Newfoundland and Labrador	
Cartwright		20 Jun 1981
Gander Int A		uncertain
Goose A		30 Oct 1971
St John's A		uncertain
Stephenville A		uncertain
Wabush Lake A	1961–2003	19 Feb 1971

[a]The 1953–2003 observation period unless otherwise specified.
[b]Estimated dewcel installation date.

[19] Models 1 and 2 are compared in order to establish if the introduction of the indicator variable I (which describes a potential step) substantially improves the fit of the model. The following F statistic is calculated:

$$F = [SSE_1 - SSE_2]/[SSE_2/(n-3)], \quad (3)$$

where SSE_1 and SSE_2 are the sums of squared errors for models 1 and 2, respectively, and n is the number of data points. The decision rule is to accept model 2 if the F statistic exceeds the 95 percentile of the F distribution with 1 and n-3 degrees of freedom [*Neter et al.*, 1985], and model 1 is accepted otherwise. In other words, when the F statistic is greater than the threshold (here equal to 4.07), model 2 is accepted and it is concluded that there is a significant step of magnitude c_2 at the dewcel installation

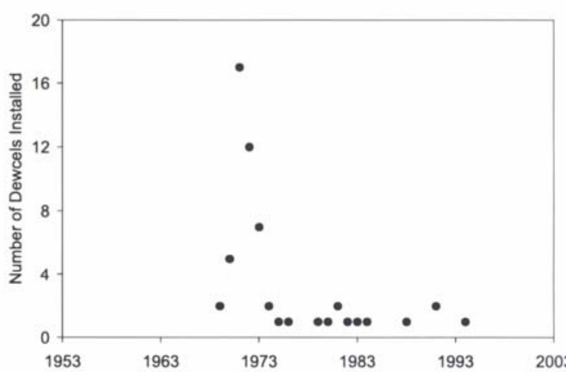

Figure 3. Dewcel installation dates at 58 stations.

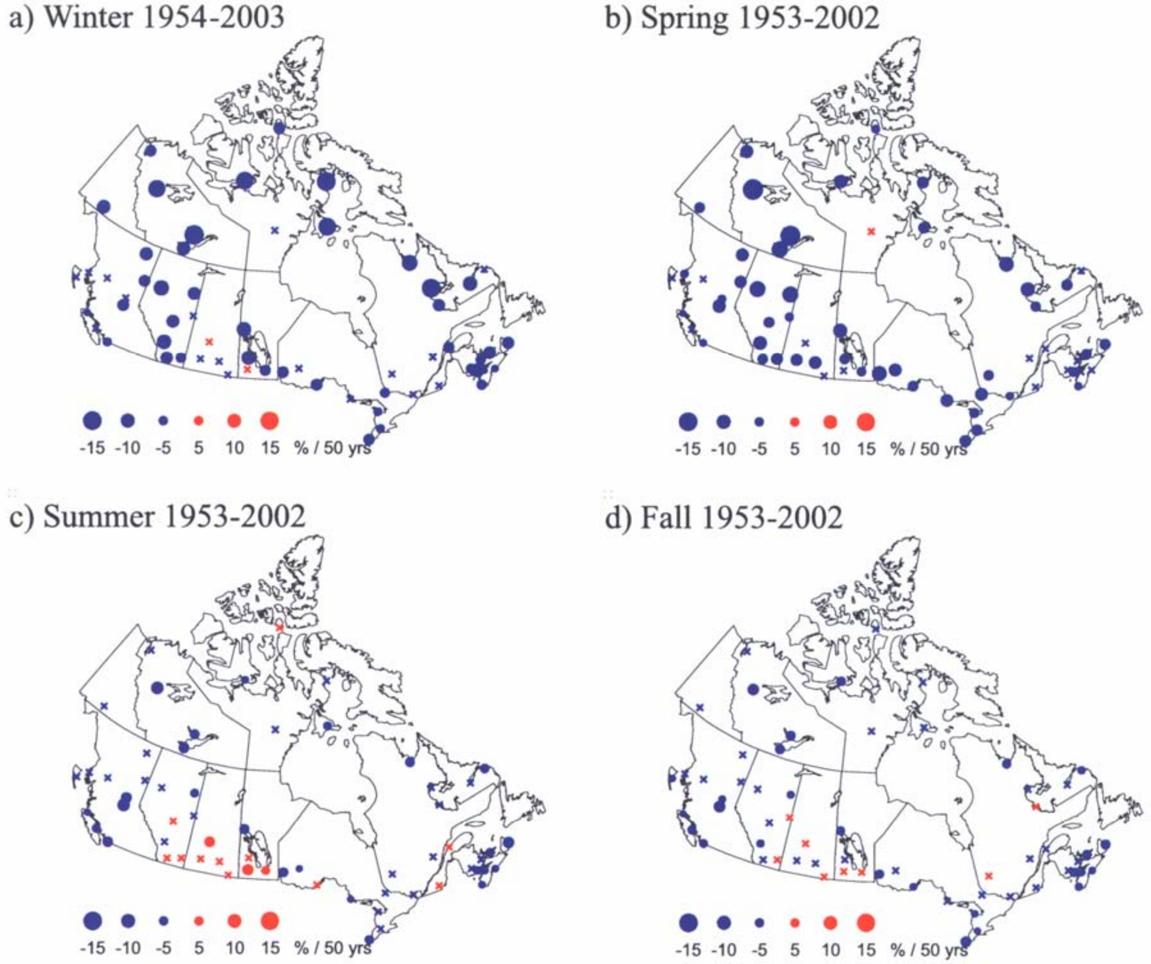

Figure 4. Seasonal trends in relative humidity obtained from model 1. Red (blue) dots represent increasing (decreasing) trends significant at the 5% level. Crosses represent trends which are not statistically significant.

date and the slope of the trend is estimated by b_2. Otherwise, there is no significant step at the installation date and the slope is given by b_1. The statistical significance of the trends is assessed using the t test at the 5% level.

6. Analysis

[20] Model 1 was first applied to the seasonal time series at individual stations. The seasonal trends are presented in Figure 4 for 61 stations (58 stations with known installation dates and three stations with no dewcel). It seems that there is a substantial decrease in relative humidity mostly during winter and spring throughout Canada. There are 42 and 46 stations with significant decreasing trends in winter and spring, respectively, and the significant trends range from −2.2% to −17.4% over the 50 years of data. For summer and fall, only 24 and 26 stations report statistically significant decreases, respectively. In addition, these trends are much weaker than those observed in the winter and spring.

[21] Model 2 was next applied to all seasonal time series, with the exception of the three stations that have not used a dewcel. Figure 5 shows the significant F statistics exceeding the threshold value. These correspond to the stations with a step occurring at the installation date. The magnitude of the F statistic is found to be proportional to the magnitude of the step. All identified steps represent a sudden decrease in relative humidity (i.e., with $c_2 < 0$) with the single exception of an increasing step that occurs at Estevan during the summer (located in southern Canada). The magnitude of the identified steps is generally larger during the winter and spring, varying from −3.5% to −18.3% and from −3.4% to −11.4%, respectively. Figure 5 clearly shows that there are more stations experiencing a dewcel step during the winter and less in the summer. Spatially, it appears that dewcel steps are associated with stations experiencing cold temper-

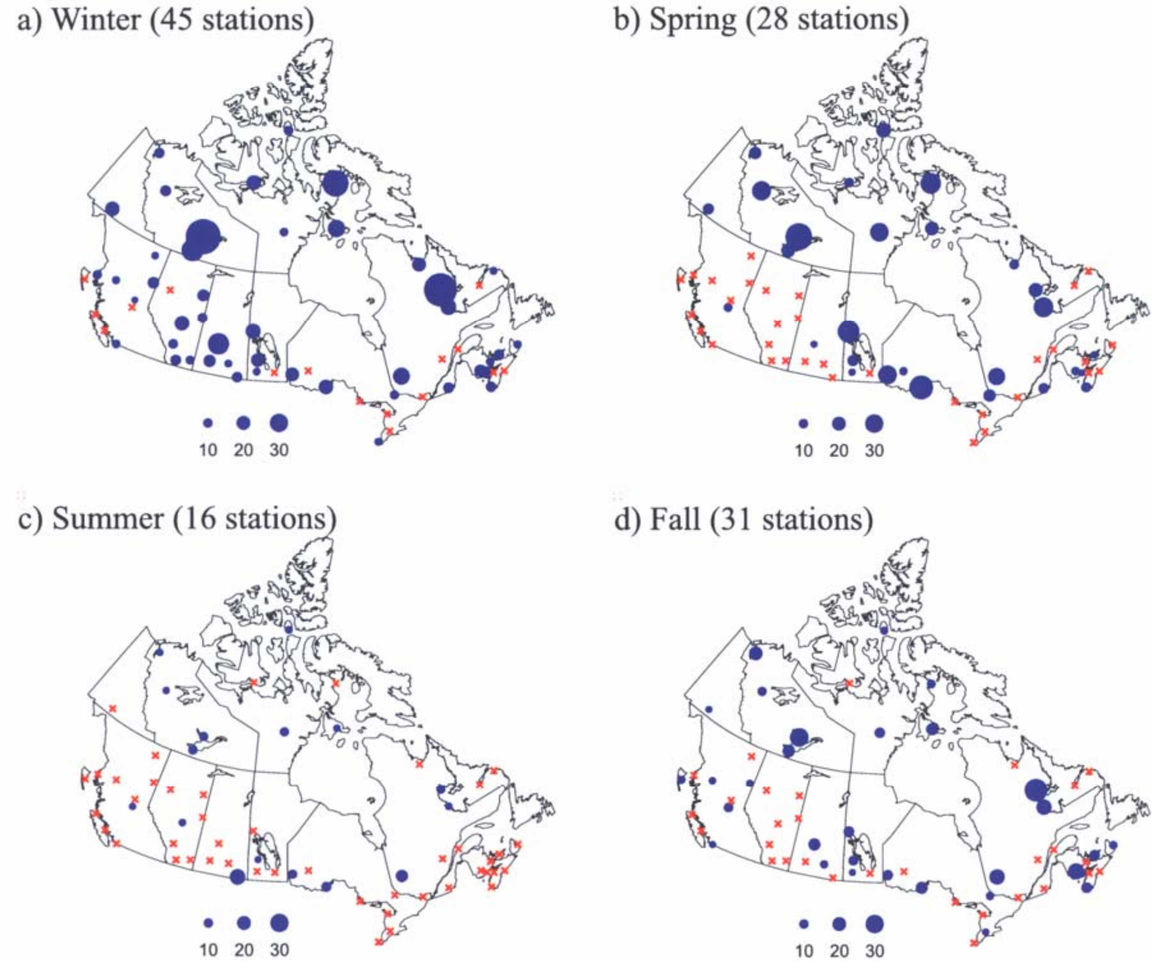

Figure 5. *F* statistic values exceeding the significant threshold (blue). The number of stations experiencing a dewcel step is given in parentheses. Crosses represent stations not having a dewcel step.

atures. Indeed, all Arctic stations north of 60°N latitude experience a dewcel step during winter and spring. In contrast, southern and coastal stations are less affected.

[22] The maps of the seasonal trends are reconsidered following the results of the *F* test. If model 2 is accepted, then the trend is derived from b_2; if it is rejected, then b_1 is used instead. Overall, Figure 6 shows much less consensus on areas of significant decreasing trends. For winter, only 10 stations remain with significant negative trends, as opposed to 42 stations in Figure 4, and the first impression of a considerable decrease in relative humidity during winter throughout Canada has changed. Spring displays only 23 stations with significant decreasing trends, however, many of them are found in the western part of the country: this area also corresponds to a strong temperature warming of about 2°C over 1950–1998 [*Zhang et al.*, 2000]. A temperature increase of 1°C will cause relative humidity to decrease by several percent assuming there was no change in the absolute moisture content of the air. The significant decreasing trends in spring relative humidity vary from −2.4% to −12.3% over the 50 years of data. The trends pattern is much weaker during the summer and fall, as observed in the original trend analysis.

7. Discussion

[23] A statistical procedure was used to detect significant steps in seasonal relative humidity at dewcel installation dates. However, it is possible that the estimated magnitude of the step identified by this procedure is not only related to the instrumental change but that a fraction of the step can also be attributed to climatic variations. Precise data adjustment would first require a laboratory comparison of psychrometers and dewcels especially at temperatures below −25°C under a variety of relative humidity. Icing of the wet bulb thermometer and air quality effects on dewcel performance should be carefully monitored to determine whether reliable adjustment of relative humidity data is in principle

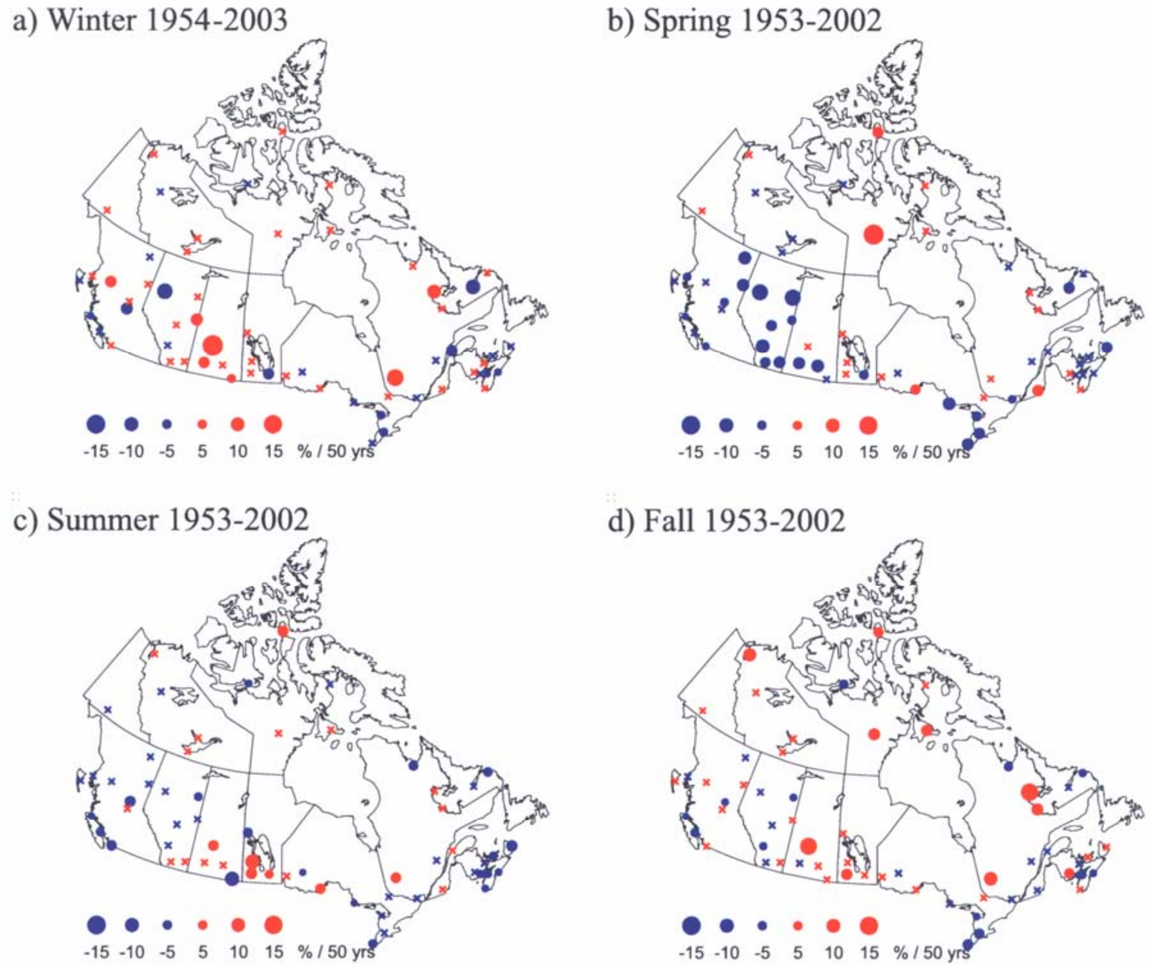

Figure 6. Seasonal trends in relative humidity following the accepted model. Red (blue) dots represent increasing (decreasing) trends significant at the 5% level. Crosses represent trends which are not statistically significant.

possible. For this reason, it is important to interpret Figure 6 with caution even if it presents an improved overall assessment of the seasonal trends. Concerns are mostly for the few stations showing a significant increase in relative humidity of over 10% after considering the "dewcel step" which is much larger than those observed in nearby stations.

8. Conclusion

[24] This work has examined hourly relative humidity data collected at 75 airport stations during 1953–2003. When the trends were originally computed on the seasonal time series, statistically significant decreases were observed in both winter and spring throughout Canada. However, it was found that a number of stations experienced a significant decreasing step coinciding with the date when the dewcel replaced the psychrometer. This is probably due to high relative humidity observations using the psychrometer when the dry bulb is coated with ice. The decreasing step accentuates the decreasing trends observed in winter and spring. It appears that these dewcel steps are especially prevalent for stations experiencing cold temperatures. Taking this effect into account, significant decreasing trends remain only in the spring. This decrease in relative humidity corresponds to the warming that has been observed in western Canada.

[25] In conclusion, it is critical to test relative humidity data for discontinuities due to changes in procedure and instruments in order to produce a reliable assessment of the climate trends. Future work will involve the analysis of trends and correlation between surface temperature, relative humidity, dew point and water vapor pressure. Comparison of these elements will be useful in determining whether temperature or moisture is the most important factor in relative humidity changes.

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