WATER VAPOR PRESSURE AND TEMPERATURE TRENDS IN NORTH AMERICAN DURING 1948-2010

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1. INTRODUCTION

Several recent studies found significant increases in surface absolute humidity that they attributed primarily to human influence. Willett et al (Willett et al, 2007) examined a homogenized gridded dataset of surface humidity for the period 1973-2003 derived from land and marine measurements of dew point temperature. The global mean surface specific humidity increased by 0.07 g/kg per decade. Multiplying this increase by the molecular weight ratio of air to water vapor and the atmospheric pressure at sea level yields an increase in water vapor pressure of 0.11 hPa per decade. Santer et al (Santer et al, 2007) examined satellite data and found atmospheric moisture over oceans increased by 0.41 kg/m^2 per decade during 1988-2006. Multiplying this by the acceleration due to gravity corresponds to a water vapor pressure increase of 0.04 hPa per decade.

Increases in specific humidity have also been reported in studies that examined station data. These records exist for a much longer time than data collected by satellites. The advantage of plotting station trends on a map as opposed to using a gridded dataset, is that it is readily evident where on Earth there are few stations, or even none at all. Dai (Dai 2006) examined surface data taken at over 15,000 weather stations and ships to calculate specific and relative humidity from 1975-2004. Relative humidity increases of 0.5 to 2% per decade occurred over the central and eastern U.S., India and western China. This and other studies have found increases in humidity to be strongly correlated with warming temperatures. Indeed, specific humidity increased by as much as 6% per decade over parts of Eurasia.

It is critical data is examined for inhomogeneities caused by changes in instruments, observation procedure etc. Robinson (Robinson 2000) examined hourly data for 178 stations in the coterminous U.S. during 1951-1990. Inhomogeneities may have affected the dewpoint trend by as much as 1 ^{o}C. The dewpoint increased by 1-2 ^{o}C per century. A 1 ^{o}C increase in dew point corresponds to a water vapor pressure increase of about 7%. Inhomogeneities were also found in a study that examined relative humidity trends in Canada. The replacement of the psychrometer by the dewcel resulted in a decrease of greater than 10% in winter relative humidity at many northern Canadian stations as is shown in Fig. 1 (van Wijngaarden and Vincent 2004).

2. DATA

This study examined over ¼ billion hourly measurements of temperature and humidity observed at 309 stations in North America during 1948-2010 (Isaac and van Wijngaarden, 2011). The data were retrieved from the Environment Canada archive which begins in 1953 and from the University Corporation for Atmospheric Research in the U.S. for the period 1948-2010. The fraction of hours for which data were present averaged 95% for the 74 Canadian stations and 80% for the 235 American stations. For each station, seasonal and annual averages were computed for every year. Seasons were defined as: winter (December – February), spring (March - May), summer (June – August) and autumn (September - November). The seasonal average was only calculated if observations existed for ≥30% of all hours and ≥25% of all hours in each 4 hour period.

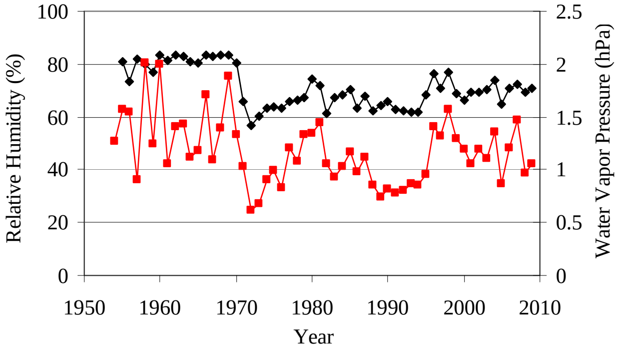

Fig. 1 Discontinuity of winter data for Schefferville, Quebec due to installation of dewcel in 1971. Black dots denote Relative Humidity while red dots represent Water Vapor Pressure.

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3. METHODOLOGY

The water vapor pressure e was computed from the relative humidity RH and temperature T measured in ^{o}C using

$$e = RH * e_s \qquad (1)$$

where the saturation water vapor pressure measured in hPa is given by

$$e_s(T) = 6.112\, e^{17.62\, T / (243.12+T)} \qquad (2)$$

The trend of each seasonally averaged time series such as shown in Fig. 3 was calculated if data existed for at least 40 years.

Data was tested for inhomogeneities such as evident in Fig. 1 using two regression models. The first model fit the data to a straight line (Vincent et al; 2007)

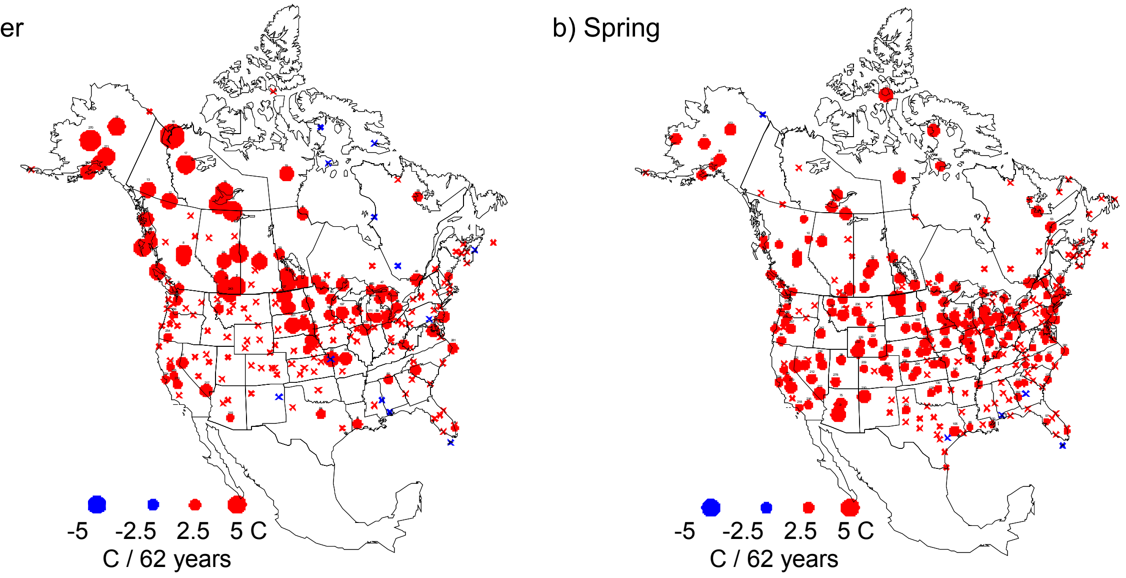
$$y_i = a_1 + b_1\, t_i + e_i \qquad (3)$$

where y_i is the seasonal temperature or water vapor pressure for year t_i. The estimate of the slope is given by b_1. The statistical significance of the trends was assessed using the t-test at the 5% level. Next, data was fitted to a straight line plus a step of magnitude c_2.

$$y_i = a_2 + b_2\, t_i + c_2\, I + e_i \qquad (4)$$

I equals zero (one), before (after) the step year t_s. Models 1 and 2 were compared using the F-statistic to determine which better fitted the data.

a) Winter b) Spring



c) Summer d) Autumn

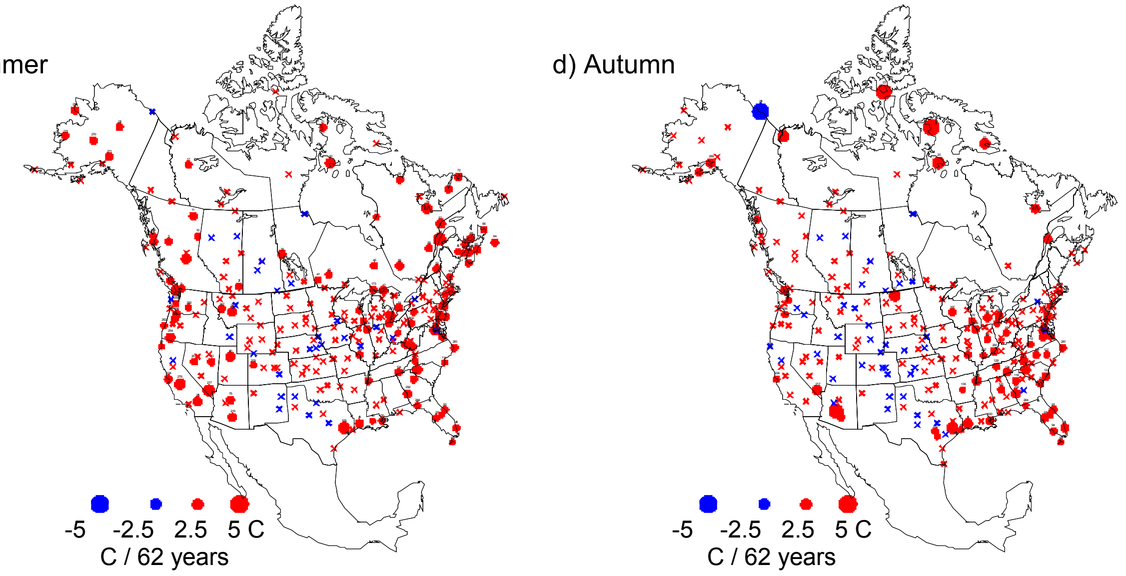


Fig. 2 Seasonal Dependence of Temperature Trends for 1948-2010 for homogeneous series as described in the text. Crosses denote trends that are not statistically significant.

4. RESULTS

Inhomogeneities were not evenly distributed throughout the year. The percentage of stations exhibiting temperature (water vapor) steps was: 28% (30%) in winter, 8% (17%) in spring, 13% (26%) in summer and 20% (23%) in autumn. The highest number occurs in winter which is reasonable as cold temperatures increase the likelihood of instrument malfunction. Inhomogeneities for both temperature and water vapor pressure were also not evenly distributed in time. For American stations, negative steps occurred most often in the 1950s and 1960s while positive steps were primarily found in later decades. In Canada, negative steps occurred with greatest frequency in the 1970s while positive steps occurred mostly in the 1990s.

Figs. 2 and 3 display trends for data not experiencing abrupt inhomogeneities. Temperature increased most in winter and to a lesser extent during spring. Stations located in the western Arctic, Canadian prairies and American Midwest experienced the largest warming. Fewer stations exhibit statistically significant water vapor pressure trends than was the case with temperature. The largest number of statistically significant increases occurred in summer at stations located in the eastern U.S.

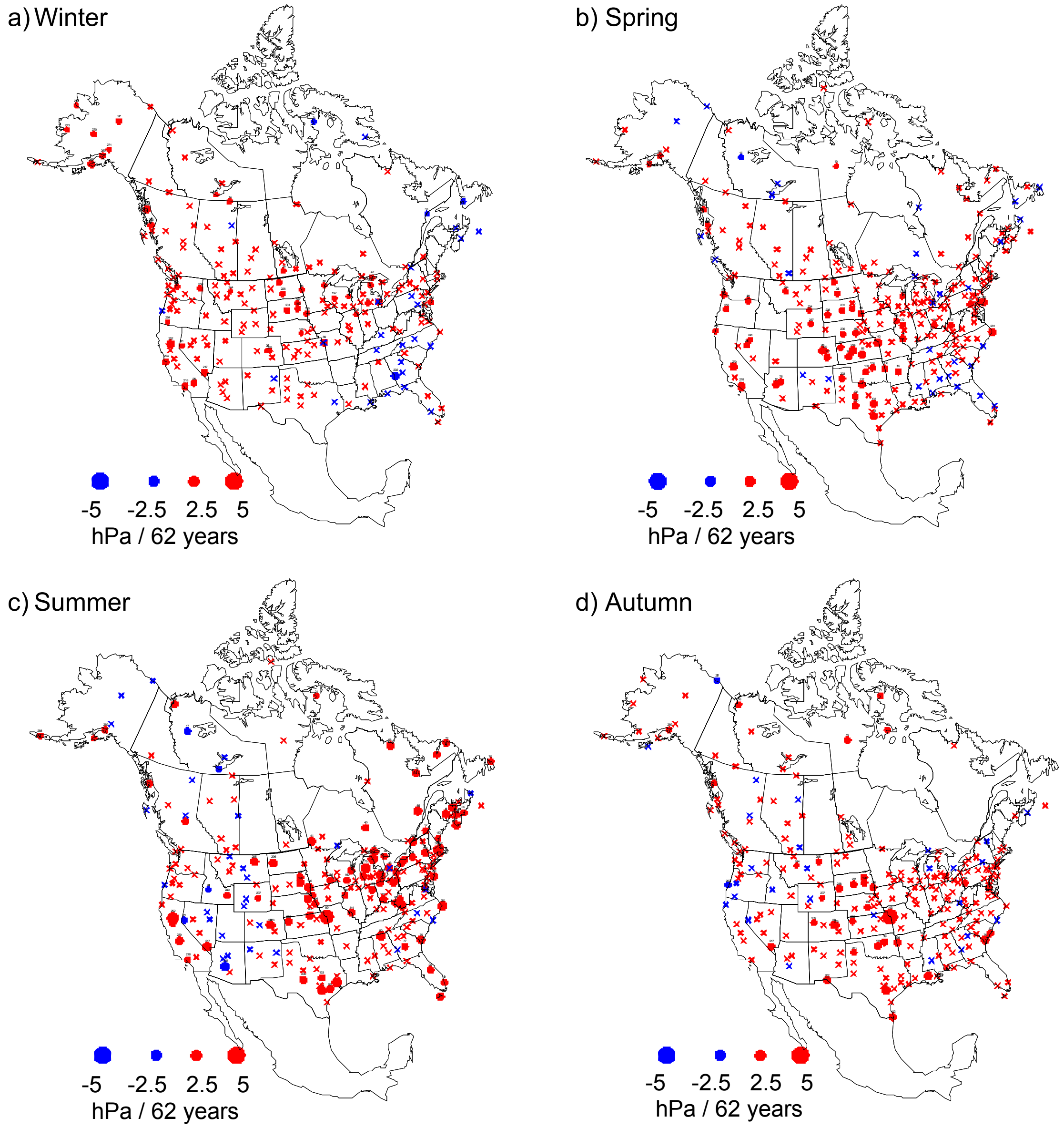


Fig. 3 Seasonal Dependence of Water Vapor Pressure Trends for 1948-2010 for homogeneous series as described in the text. Crosses denote trends that are not statistically significant.

The seasonal trends averaged over all stations are summarized by Table I. The percentage change in water vapor pressure was obtained using the average seasonal water vapor pressure values. Higher trends were found for the 1981-2010 period. The average annual temperature decadal trend increased to 0.23 °C from 0.20 °C for 1948-2010 while the water vapor pressure trend nearly doubled to 0.15 hPa per decade. Temperature trends were somewhat larger at night than during the day. There are indications that water vapor trends affecting metropolitan areas having populations of over 1 million, were about 50% larger than those affecting rural or small town stations.

Table I. Seasonal Dependence of Averaged Trends during 1948-2010 for Data not Experiencing Inhomogeneities.

Season	Temperature Trend °C/decade	Water Vapor Pressure Trend	
		hPa/decade	%/decade
Winter	0.30	0.04	0.8
Spring	0.24	0.06	0.7
Summer	0.13	0.11	0.7
Autumn	0.11	0.07	0.7
Average	0.20	0.07	0.7

5. CONCLUSIONS

It is important to check data for inhomogeneities that can significantly affect trends. Examination of hourly temperature and water vapour pressure data show over a quarter of 309 stations located in North America in winter and a lesser but nonnegligible number in the other seasons, are so affected. Positive and negative steps are not evenly distributed throughout the 1948-2010 observation period.

Statistically significant warming has notably affected the Western Arctic, Canadian prairies and the American Midwest during winter. Changes in surface water vapour pressure are less dramatic. This does not correspond to the expectation that warmer temperatures are automatically associated with increased water vapour pressure. Increasing water vapor pressure trends were also found in previous studies with the exception of decreasing winter humidity observed by Robinson (Robinson 2000). However, the average trend magnitude found in this work was smaller than found by studies that only examined data collected in the later decades of the 20th century (Dai 2006; Willett et al 2007; Santer et al; 2007). This work did find larger trends for both water vapor pressure and temperature during 1981-2010. It is not clear whether this acceleration of warming will continue. This underscores the difficulty in extrapolating trends based on only one or two decades of data.

In conclusion, water vapor pressure and temperature were found to increase at a large majority of 309 stations located throughout North America. The average magnitude of the water vapor pressure trends during 1948-2010 is +0.07 hPa per decade or +0.7% per decade while the average temperature increase is 0.20 °C per decade. The number of stations exhibiting statistically significant changes in water vapor pressure is fewer than is the case when considering temperature.

6. Acknowledgements

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7. References

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