Surface Water Vapor & Temperature Trends in North America during 1948-2010

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A number of studies have found significant changes of temperature[1] and humidity[2] on decadal time scales and attributed much of these changes to human influence[3,4,5]. A warmer atmosphere is expected to significantly affect the Earth's climate. The Clausius-Clapeyron equation shows that saturation vapor pressure increases exponentially with temperature. Increasing water vapor pressure may increase precipitation[6,7] and affect storm intensity[8,9,10]. One group found the global mean water vapor pressure increased by 0.11 hPa per decade and was strongly correlated with temperature increases[5]. Another group examined data taken using a microwave satellite imager and found the total atmospheric moisture content over oceans increased by 0.04 hPa per decade during 1988-2006[6]. A third group examined data taken at over 15,000 weather stations and ships during 1975-2004. Relative humidity increases of 0.5 to 2% per decade were found over the central and eastern U.S., India and western China that were associated with an increase in temperature and absolute humidity[7]. The latter increased by as much as 6% per decade over parts of Eurasia.

This study examined over ¼ billion hourly records of temperature and relative humidity observed at 309 stations located throughout North America during 1948-2010[11]. The trends found are smaller than those reported by studies that only considered one or two decades of data[5-7]. In addition, the changes in humidity are not well correlated geographically or seasonally with increasing temperatures.

Hourly temperature and relative humidity observations are available from Environment Canada and from the University Corporation for Atmospheric Research (UCAR) in the U.S.. 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. The seasonal average was only computed if observations existed for ≥30% of all hours and ≥25% of all hours in each 4 hour period. The water vapor pressure p_w was computed by multiplying the relative humidity RH by the saturation water vapor pressure measured in hPa and given at temperature T by[12]

$$p_{sat}(T) = 6.112\, e^{17.62\, T / (243.12+T)} \qquad (1)$$

The trend of each seasonally averaged time series was calculated if data existed for at least 40 years. The data was tested for inhomogeneities using two regression models. The first model fit the data to a straight line

$$y_i = a_1 + b_1\, t_i + e_i \qquad (2)$$

where y_i is the seasonal temperature or water vapor pressure for year t_i. A fit to a higher order polynomial was not considered as climate change is as yet insufficiently large to justify inclusion of nonlinear effects. A t-test compared the mean of the residuals e_i when the data was fit to a line or to a constant at the 5% statistical significance level. Next, data was fitted to a straight line plus a step of magnitude c_2.

$$y_i = a_2 + b_2\, t_i + c_2\, I + e_i \qquad (3)$$

I equals zero (one), before (after) the step year t_s. A F-test, which compares the standard deviations of two populations, determined whether the data was better fitted by (2) or (3). Fig. 1 shows a plot of the winter relative humidity at Schefferville, Quebec. The 20% drop in 1971 coincided with the replacement of the psychrometer with the dewcel. Nearly 75% of Canadian stations installed dewcels during 1969-1973 and their observed winter relative humidity exhibits a similar downward step[13].

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 during winter which is reasonable as cold temperatures increase the likelihood of instrument malfunction. Positive and negative steps, for both temperature and water vapor pressure were also not evenly distributed in time.

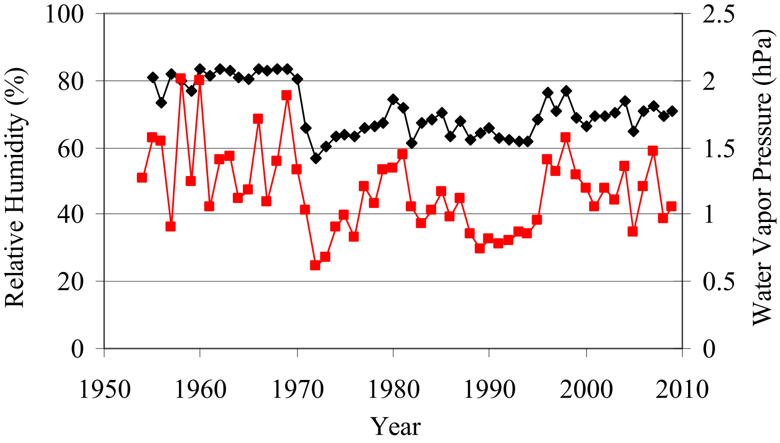

Fig. 1 Discontinuity of Winter Relative Humidity (black dots) and Water Vapor Pressure (red dots) for Schefferville, Quebec.

For the American stations, negative steps occurred predominantly 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 were found most often in the 1990s.

It is therefore important to consider trends for data not experiencing inhomogeneities. For the period 1948-2010, stations located in the western Arctic, Canadian prairies and American Midwest experienced the largest warming in winter and spring. For water vapor pressure, fewer stations exhibit statistically significant trends than was the case with temperature. The largest number of statistically significant increases occurred in summer at stations predominantly located in the eastern half of the U.S. The decadal temperature (water vapor pressure) trends averaged over all stations are 0.30 (0.04), 0.24 (0.06), 0.13 (0.11) and 0.11 (0.07) ^{o}C (hPa) in the winter, spring, summer and autumn, respectively. The percentage change of water vapor pressure, found by dividing the trends by the seasonal average pressure, was nearly constant for all seasons at +0.7% per decade. This is about half the value expected if the relative humidity had remained constant.

In conclusion, it is important to check data for inhomogeneities that can significantly affect trends. The trends found for 1948-2010 are smaller than those reported by studies that only considered one or two decades of data[5-7]. Our work also found larger trends for 1981-2010. The average annual temperature decadal trend increased to 0.23 ^{o}C from 0.20 ^{o}C for 1948-2010 while the water vapor pressure trend nearly doubled to 0.15 hPa per decade.

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