# A Statistical Comparison of Weather Stations in Carberry, Manitoba Canada

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***Abstract***

There are three weather stations co-located at a site near Carberry, Manitoba operated by Environment Canada, Manitoba Agriculture Food and Rural Initiative (MAFRI) and WeatherFarm (Canadian Wheat Board/Earth Networks). This situation provides the opportunity to compare weather data and results across the different types of stations used in the three different networks. Multiple comparisons between the weather stations measuring different weather variables will be presented.

Study results based on actual sensor data comparisons in Carberry for hundreds of hourly observations for the month of February and May, 2011 and July, 2010 clearly illustrate that there is little statistical difference in the measured variables between the Environment Canada station (control) versus the WeatherFarm station (measured) for temperature, dew point, precipitation and, in most cases, relative humidity, as well as wind speed (February 2011). Additionally, precipitation measurements were also compared between all three stations – WeatherFarm, MAFRI and Environment Canada – and were found to be significantly correlated in all cases.

Precipitation measurements for the liquid (rainy) season were also compared between the three station rain gauges, and little statistical difference was found in tipping buckets in relationship to weighing gauge measurements. Further an extreme rainfall event in Saskatchewan is analyzed providing proof that tipping bucket gauges do not underestimate heavy rainfall events. The WeatherFarm network provided highly localized weather data during the storm to capture convection precipitation. This study demonstrates that real-time weather information from the WeatherFarm station sensors is complementary to the Environment Canada stations data, and provides weather information with the granularity necessary for real-time weather event management and decision making relative to flood prediction, monitoring and forecasting. This data has also been used to increase the timeliness and accuracy of watches and warnings and special weather statements issued by Environment Canada.

## *Overview*

There are three weather stations collocated at a site near Carberry, Manitoba, Canada. These weather stations are operated by Environment Canada; Manitoba Agriculture, Food and Rural Initiative (MAFRI); and WeatherFarm. This situation provides the opportunity to compare data and results across the different types of stations used in the three different weather networks.

This paper will provide details into the methodology and results of statistical comparisons of sensors at the Carberry location. One comparison was performed utilizing hundreds of observations during the months of July 2010, February and May 2011. These observation variables included: temperature, dew point, precipitation and humidity. Further analysis was performed comparing wind speed data collected from WeatherFarm sensors in comparison to those operated by Environment Canada. Finally, precipitation measurements for the liquid season were compared to both MAFRI and Environment Canada, and were also examined under an extreme rainfall event on June 17, 2011 in southern Saskatchewan (10 to 110+ mm).

The results of the comparison suggest that there is little statistical difference in the weather observations taken by the stations despite the differences in the equipment and the data gathering

systems employed. The results also suggest that data gathered from the WeatherFarm network is complementary to the data gathered by the Environment Canada network.

***Methodology***

The three weather stations are located within 50 to 75 feet of each other. In Figure 1, the WeatherFarm weather station is in the centre of the picture. To the left, is the MAFRI station and rain collector. To the right is another Davis weather station that is privately owned and not included in the study. The Environment Canada sensors are all located behind the MAFRI and WeatherFarm sensor equipment. (From left to right: Rain collector, weighing gauge, temp/humidity sensor, and anemometer).

It should be noted when reviewing the data below that the Environment Canada and WeatherFarm weather stations were installed according to WMO guidelines, with the installation height of the temperature and relative humidity sensors at approximately 125cm above the ground. By contrast, MAFRI temperature and relative humidity sensors are located 30cm above the ground for a specific application – disease modelling for potatoes.

Additionally, the WeatherFarm weather network, operated by Earth Networks, applies automated data quality control checks built by Earth Networks to all weather data to ensure the quality of data flowing into and out of the network.

***This study assumes that the Environment Canada sensors have been calibrated and are the correct reading (i.e. measured and not the predicted values in the statistical test). Data was compared based on 1 hour updates, since Environment Canada reports at this interval (WeatherFarm stations update every 2 ½ seconds). Comparisons were done between raw WeatherFarm data, while Environment Canada data has either had preliminary QA/QC or has been fully QA/QC'd. MAFRI data used in the graphs/analysis was also raw.***

Hourly temperature, relative humidity, dew point, 2-minute average wind speed, and daily precipitation observations were compared for the months of July and February 2010, and May 2011. A number of statistical tests were run on the data from both WeatherFarm and Environment Canada sensors. The techniques used can be classified as relative and absolute error indices.

**Relative error indices include**: the d = index of agreement, and the $R^2$ = coefficient of determination. A value of 1.0 for both d and $R^2$ indicates perfect agreement, while values of 0.95 and higher demonstrate significant correlation.

Unlike the relative error measures, the absolute error measures can be expressed in units of the measured data.

**Absolute error indices include**:

- Root Mean Square Error (RMSE). The RMSE is the square root of the mean squared deviations. It provides the weighted variations in errors (residuals) between the measured (Environment Canada) and predicted (WeatherFarm) values.

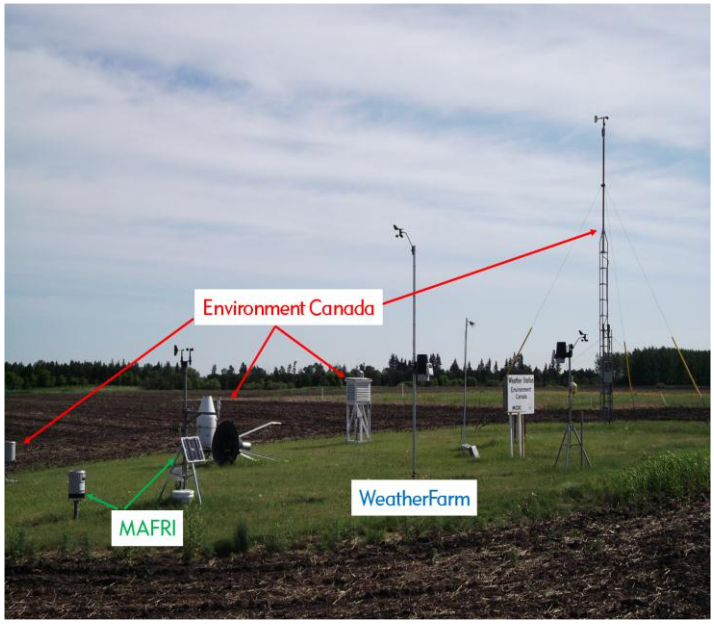


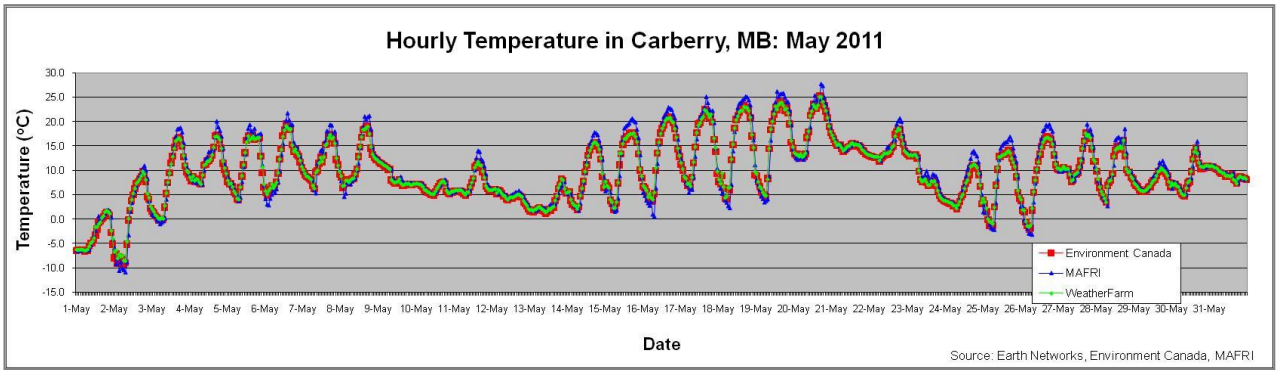

Figure 1: Weather stations located at Carberry, Manitoba

- Mean Absolute Error (MAE). The MAE gives the average of the absolute differences (error) between the measured and predicted values. The MAE is a linear score that gives equal weight to both small and larger errors and does not consider the direction of errors.

- Mean Bias Error (MBE) The MBE test is an indicator of whether the model (WeatherFarm) is over-predicting or under-predicting the measured (Environment Canada) values. Values of 0.0 indicate equal distribution between positive and negative errors.

### *Results*

### May 2011 Hourly Temperatures

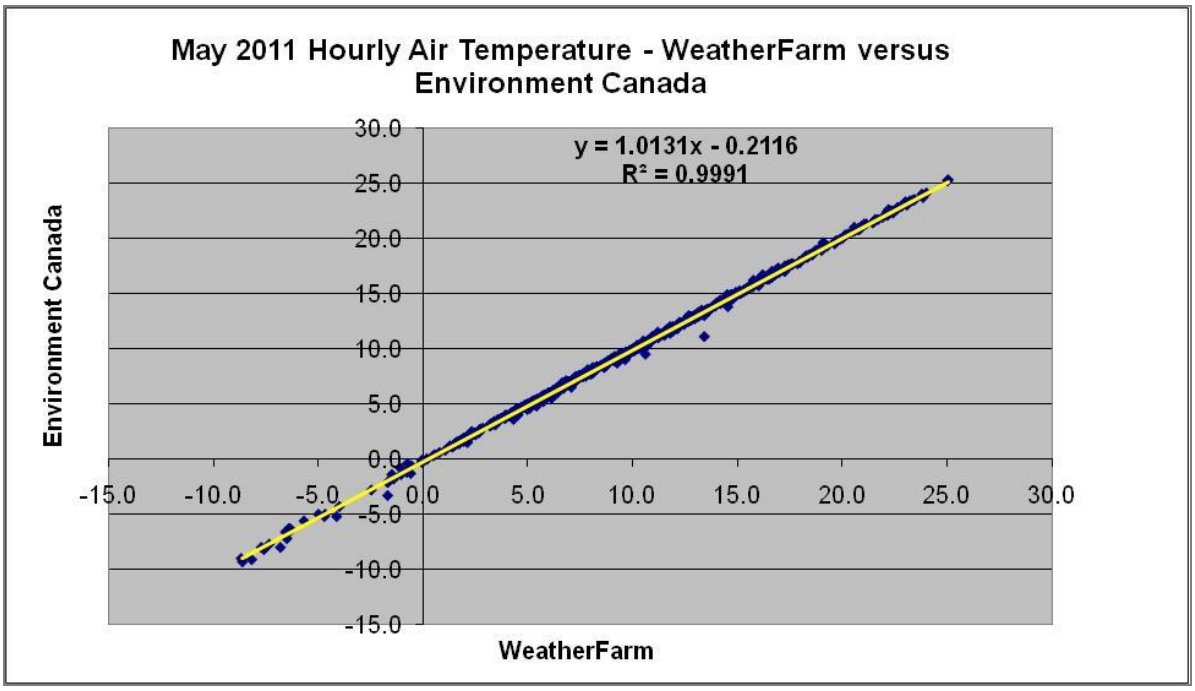



Graph 1: Comparison of Hourly Temperatures at Carberry, Manitoba: May 2011; sample size is 744 hourly observations

- The relative indices ($R^2$=0.9991 and d=0.99998) indicated that the predicted temperatures (WeatherFarm) were in very close agreement to the measured (Environment Canada) results.
- The RSME between the measured and predicted values is 0.4 $^{o}$C.
- The comparison of about 744 hourly observation for the month of May, the MAE is 0.1554 $^{o}$C.
- The MBE value of 0.096 $^{o}$C indicates that WeatherFarm is very slightly over estimating temperature.

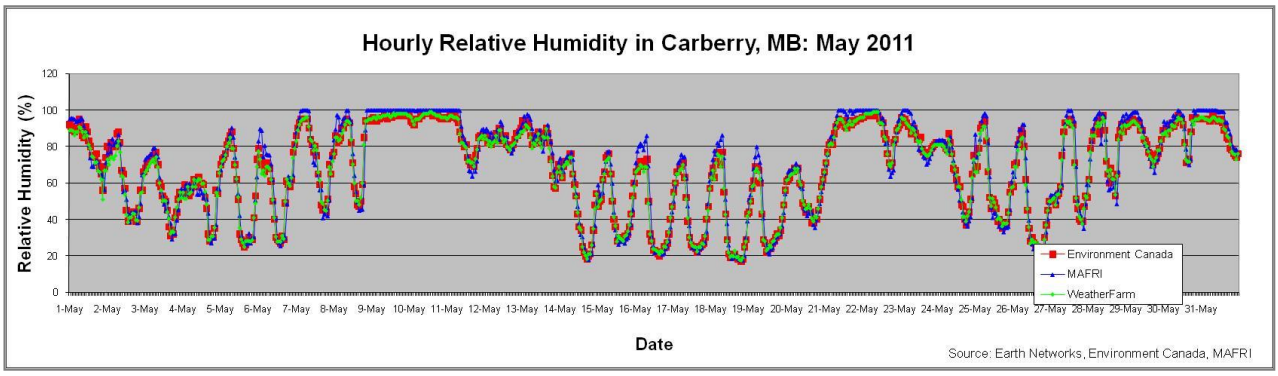
| | | |
|---|---|---|
| Average Difference | 0.0969 | |
| $R^2$ | 0.9991 (0 to 1.0) | |
| d | 1.0000 (0 to 1.0) | |
| RMSE | 0.4007 (°C) | |
| MAE | 0.1554 (°C) | |
| MBE | 0.0969 (°C) | |
| Paired T-test | 0.0000 | |
| | **WeatherFarm** | **EC** |
| Average | **9.71** | **9.62** |
| Standard Deviation | 6.2055 | 6.2936 |
| Standard Error Mean | 0.2275 | 0.2307 |
| Coefficient of Variance | 63.928.1 | 65.4019 |

Table 1: Statistical analysis of the WeatherFarm versus Environment Canada May 2011 hourly temperatures at Carberry




Graph 2: Linear regression analysis of hourly WeatherFarm versus Environment Canada May 2011 temperatures

## May 2011 Hourly Relative Humidity



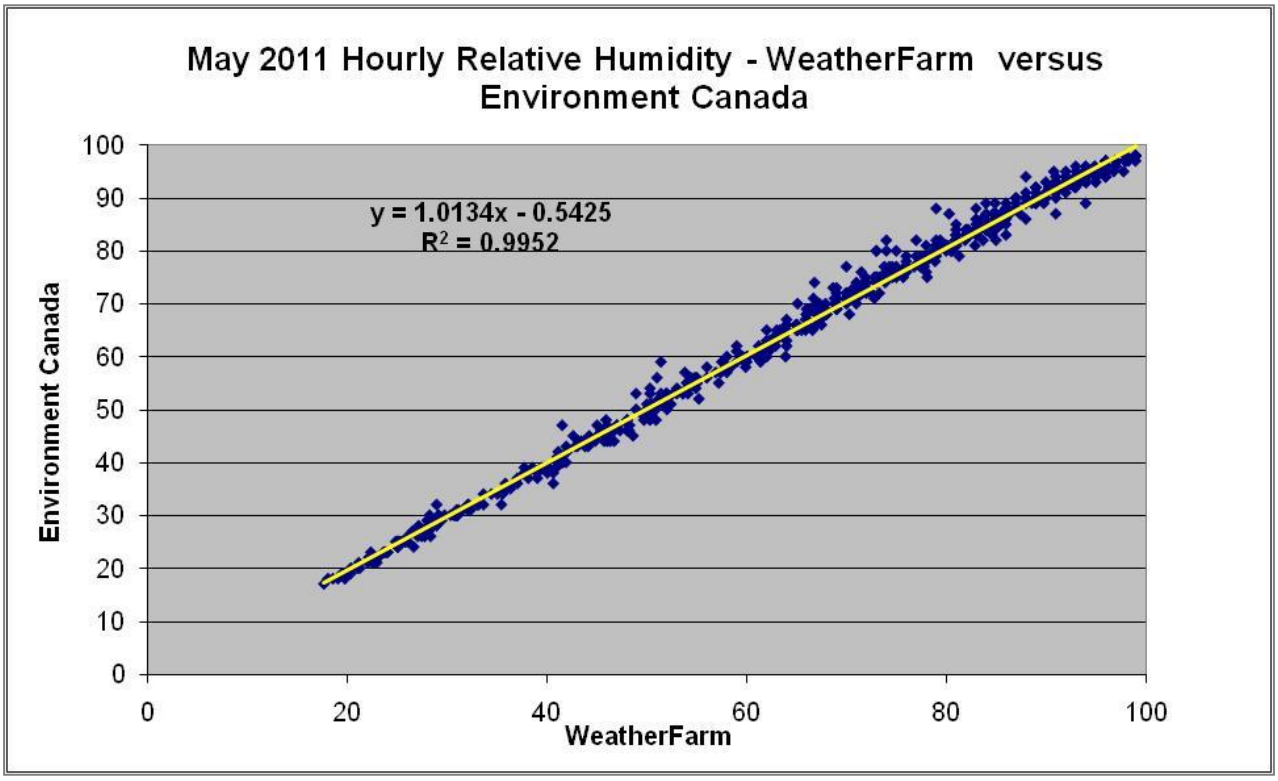

Graph 3: Comparison of Hourly Relative Humidity at Carberry, Manitoba: May 2011; sample size is approximately 744 observations

- The relative indices ($R^2$=0.9952 and d=0.9987) indicated that the predicted relative humidity (WeatherFarm) values were in very close agreement to the measured (Environment Canada) results.
- The RSME between the measured and predicted values is 1.683 %.
- For the comparison of about 744 hourly observations for the month of May, the MAE error is 1.1615%.
- The MBE value of -0.3703 % indicates that WeatherFarm is very slightly under estimating relative humidity.

| | |
|---|---|
| Average Difference | -0.3703 |
| $R^2$ | 0.9952 (0 to 1.0) |
| d | 0.9987 (0 to 1.0) |
| RMSE | 1.6835 (%) |
| MAE | 1.1615 (%) |
| MBE | -0.3703 (%) |
| Paired T-test | 0.0000 |

| | WeatherFarm | EC |
|---|---|---|
| Average | **67.88** | **68.25** |
| Standard Deviation | 23.19607 | 23.5290 |
| Standard Error Mean | 0.8491 | 0.8626 |
| Coefficient of Variance | 34.1189 | 34.4734 |

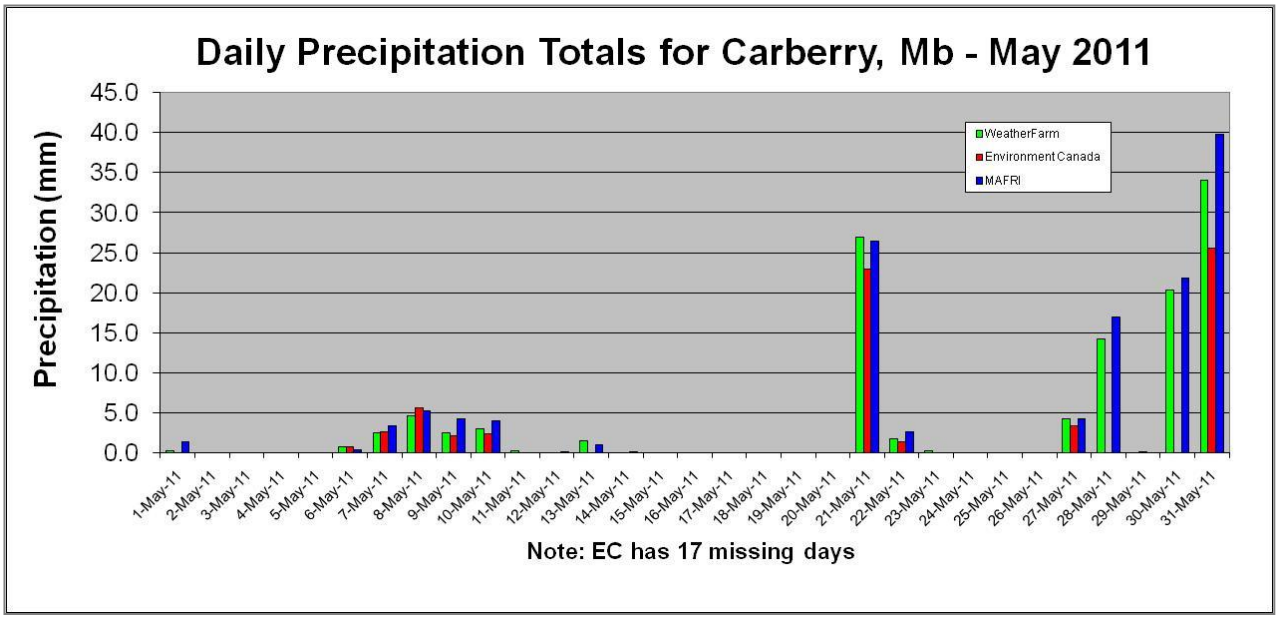
Table 2: Statistical analysis of the WeatherFarm versus Environment Canada May 2011 hourly relative humidity at Carberry




Graph 4: Linear regression analysis of hourly WeatherFarm versus Environment Canada May 2011 relative humidity percentages

### May 2011 Daily Precipitation Totals

Note: It was not possible to undertake hourly precipitation analysis as only daily values were available from Environment Canada. The study was also hindered because the Environment Canada rain gauge was missing 17 days of readings for the month of May and the observations on other days were questionable. The overwinter Environment Canada precipitation gauge at Carberry was missing data between November 26, 2010 and April 26, 2011.



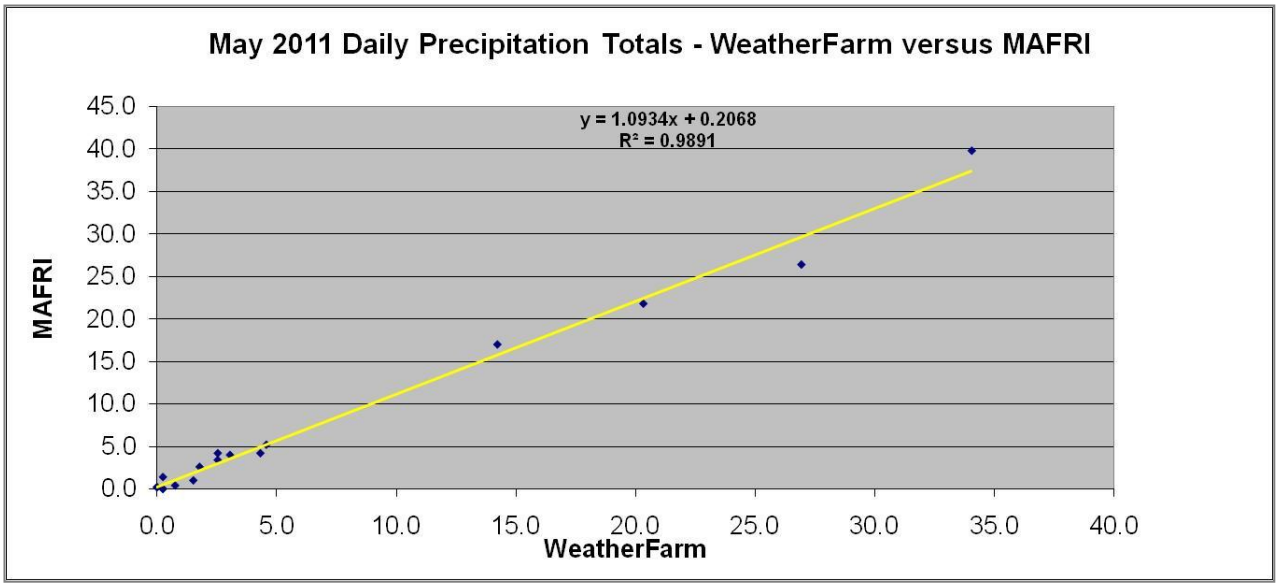

Graph 5: Comparison of daily precipitation measurements at Carberry, Manitoba: May 2011

- WeatherFarm data was compared to MAFRI daily rain gauge data. The relative indices ($R^2$=0.9891 and d=0.9934) indicated that the predicted daily precipitation (WeatherFarm) values were in very close agreement to the measured (MAFRI) observation.
- The RSME between the measured and predicted values is 1.7282 mm.
- For the comparison of 17 daily observations for the month of May, the MAE is 1.0888 mm.
- The MBE value of -0.8512 mm indicates that WeatherFarm is very slightly under estimating precipitation according to the MAFRI site at Carberry. **It should be noted that precipitation varies greatly over short distances and therefore, as expected, no two rain gauges will have exactly the same readings.**

| | |
|---|---|
| Average Difference | -0.8512 |
| $R^2$ | 0.9891 (0 to 1.0) |
| d | 0.9934 (0 to 1.0) |
| RMSE | 1.7282 (mm) |
| MAE | 1.0888 (mm) |
| MBE | -0.8512 (mm) |

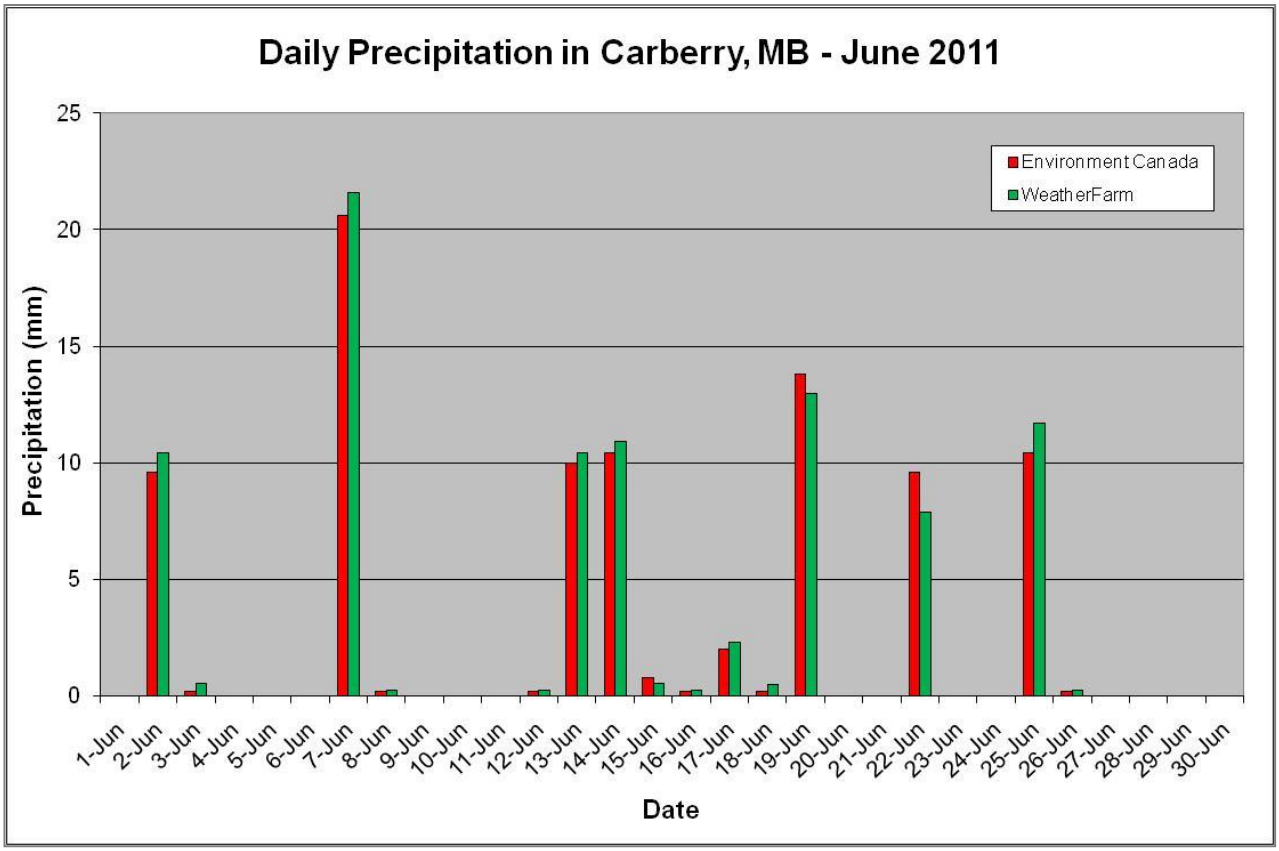
| | WeatherFarm | MAFRI |
|---|---|---|
| Average | **6.90** | **7.75** |
| Standard Deviation | 10.4783 | 11.5197 |
| Standard Error Mean | 2.5414 | 2.7939 |
| Coefficient of Variance | 151.8213 | 148.5845 |

Table 3: Statistical analysis of the WeatherFarm versus MAFRI May 2011 daily precipitation at Carberry




Graph 6: Linear regression analysis of WeatherFarm versus MAFRI daily precipitation values for May 2011

The precipitation data for June 2011 was also analyzed as we were unable to compare WeatherFarm directly with Environment Canada for the month of May 2011.



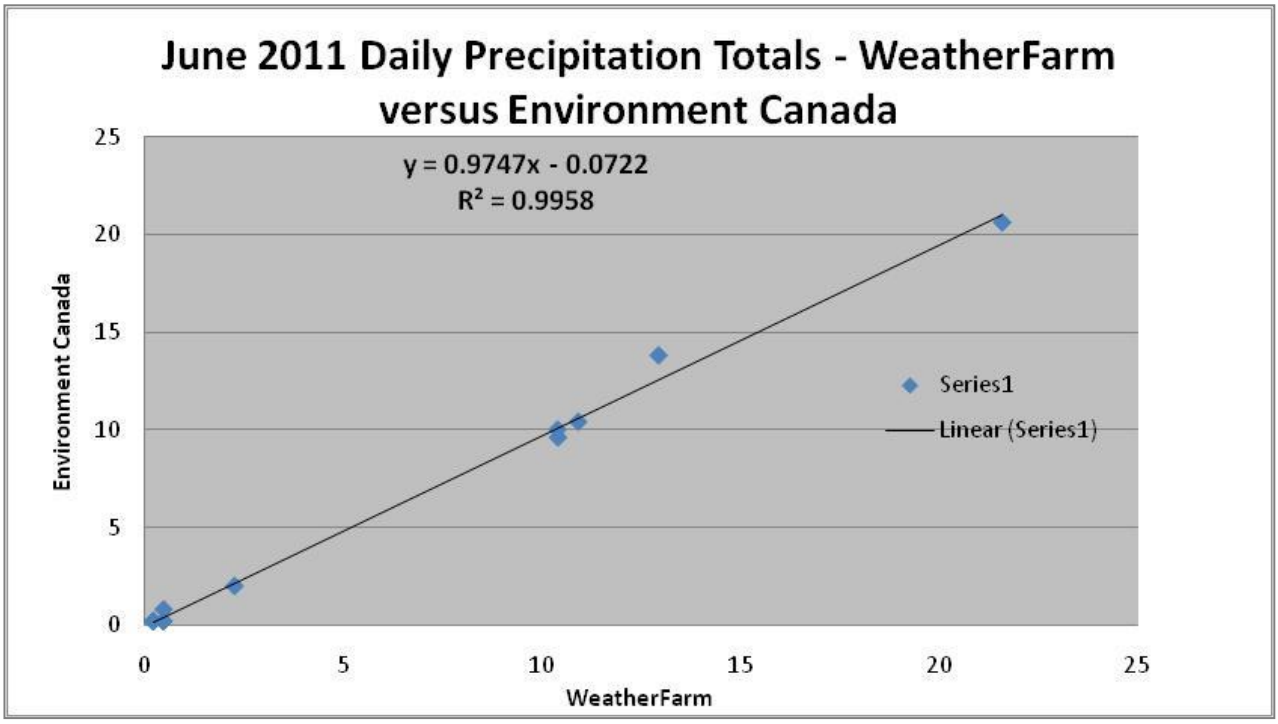

Graph 7: Comparison of daily precipitation measurements at Carberry, Manitoba: June 2011

- The relative indices ($R^2$=0.9958 and d=0.9968) indicated that the predicted daily precipitation (WeatherFarm) values were in very close agreement to the measured (Environment Canada) observation.
- The RSME between the measured and predicted values is 0.5153 mm.
- For the comparison of 15 daily observations for the month of June, the MAE is 0.5333 mm.

- The MBE value of 0.2040 mm indicates that WeatherFarm is very slightly over estimating precipitation according to the Environment Canada site at Carberry. **It should be noted that precipitation varies greatly over short distances (see study below) and therefore as expected no two rain gauges will have exactly the same readings.**

| | | |
|---|---|---|
| Average Difference | 0.2040 | |
| $R^2$ | 0.9958 (0 to 1.0) | |
| d | 0.9968 (0 to 1.0) | |
| RMSE | 0.7220 (mm) | |
| MAE | 0.5333 (mm) | |
| MBE | 0.2040 (mm) | |
| | **WeatherFarm** | **EC** |
| Average | **6.07** | **5.87** |
| Standard Deviation | 6.6762 | 6.5581 |
| Standard Error Mean | 1.7238 | 1.6933 |
| Coefficient of Variance | 109.9751 | 111.7852 |

Table 4: Statistical analysis of the WeatherFarm versus Environment Canada June 2011, daily precipitation at Carberry




Graph 8: Linear regression analysis of daily WeatherFarm versus Environment Canada June 2011 precipitation values

### Spatial Variability in Precipitation Measurements

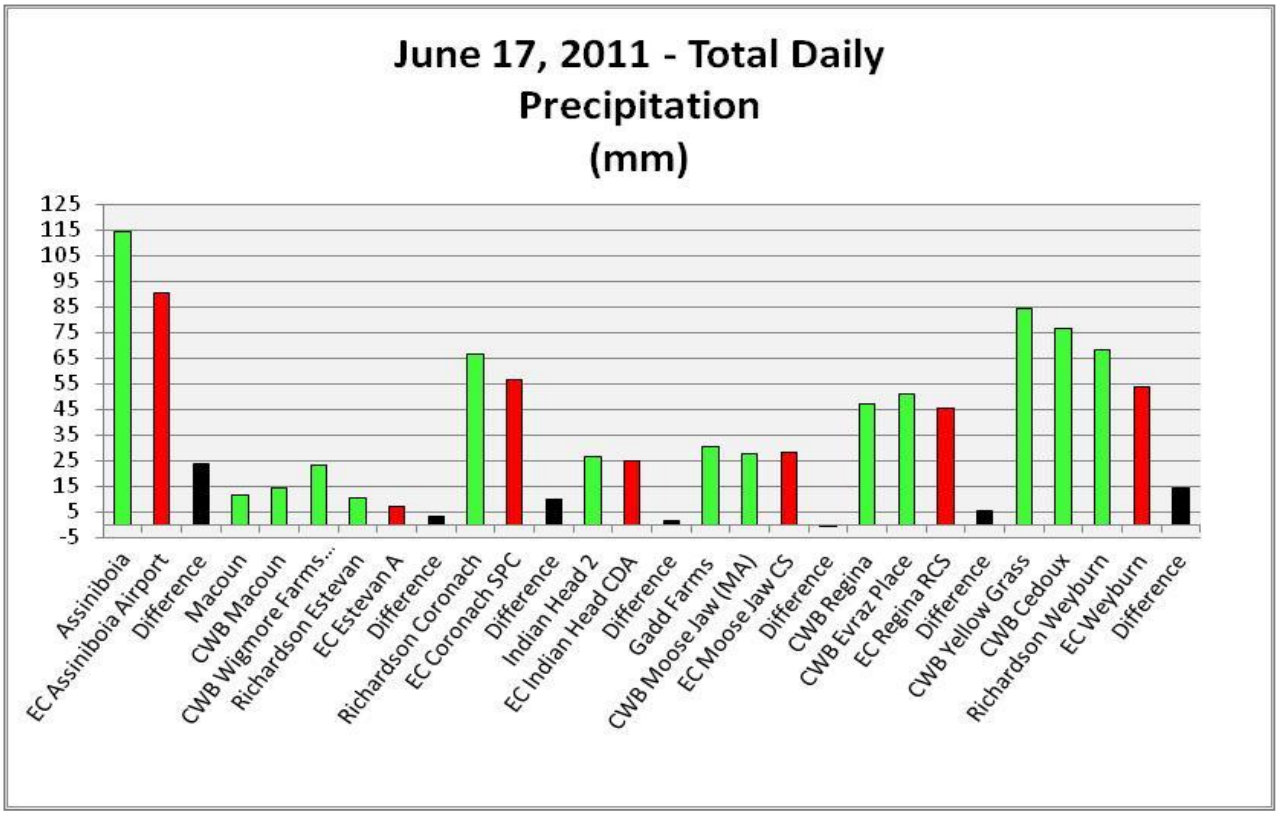
A significant precipitation event occurred on June 17, 2011 in southern Saskatchewan. Many locations recorded a deluge of rainfall in a 24 hour period leading to flooding on the Souris River. There has been a suggestion that the WeatherFarm weather stations (i.e. tipping bucket gauges) tend to under estimate precipitation amounts when heavy rainfall events occur (> 30 mm per day).

For the June 17 storm there were 7 WeatherFarm stations within 2 to 12km of Environment Canada sites (Assiniboia, Estevan, Coronach, India Head CDA, Moose Jaw, Regina and Weyburn). In all but one case (Moose Jaw, amount was 0.56 mm lower), the WeatherFarm

stations recorded more (1.74 to 23.85 mm higher) precipitation than those at the corresponding Environment Canada sites.

| Network | Station Name | Town | Tot. Daily Precip.(mm) |
|---|---|---|---|
| WeatherFarm | Assiniboia | Assiniboia | 114.55 |
| EC | EC Assiniboia Airport | Assiniboia | 90.70 |
| | **Difference** | | **23.85** |
| WeatherFarm | Macoun | Macoun | 11.43 |
| WeatherFarm | CWB Macoun | Macoun | 14.48 |
| WeatherFarm | CWB Wigmore Farms | Estevan | 23.37 |
| WeatherFarm | Richardson Estevan | Estevan | 10.67 |
| EC | EC Estevan A | Estevan | 7.20 |
| | **Difference** | | **3.47** |
| WeatherFarm | Richardson Coronach | Coronach | 66.55 |
| EC | EC Coronach SPC | Coronach | 56.60 |
| | **Difference** | | 9.95 |
| WeatherFarm | Indian Head 2 | Indian Head | 26.64 |
| EC | EC Indian Head CDA | Indian Head | 24.90 |
| | **Difference** | | **1.74** |
| WeatherFarm | Gadd Farms | Moose Jaw | 30.23 |
| WeatherFarm | CWB Moose Jaw (MA) | Moose Jaw | 27.94 |
| EC | EC Moose Jaw CS | Moose Jaw | 28.50 |
| | **Difference** | | **-0.56** |
| WeatherFarm | CWB Regina | Regina | 46.99 |
| WeatherFarm | CWB Evraz Place | Regina | 50.80 |
| EC | EC Regina RCS | Regina | 45.50 |
| | **Difference** | | **5.30** |
| WeatherFarm | CWB Yellow Grass | Yellow Grass | 84.07 |
| WeatherFarm | CWB Cedoux | Cedoux | 76.71 |
| WeatherFarm | Richardson Weybum | Weybum | 68.07 |
| EC | EC Weybum | Weybum | 53.60 |
| | **Difference** | | **14.47** |

Table 5: Comparison of WeatherFarm versus Environment Canada precipitation amounts for June 17, 2011 storm




Graph 9: Comparison of WeatherFarm versus Environment Canada Precipitation amounts for June 17 storm in southern Saskatchewan

The spatial variability in convective precipitation amounts are an order of magnitude higher than the error associated with any one sensor type. This is clearly evident from a number of precipitation events in Manitoba. On June 13, an intense convective thunderstorm produced rainfall amounts of 87 mm in one hour at Balmoral, Manitoba. This event was captured on the WeatherFarm network (maximum value 87 mm), was partially captured on the MAFRI network (maximum value 57.9 mm) and missed on the Environment Canada network (maximum 5.5 mm). This one event caused the Netley Creek to rise by 4 ½ feet in a day.

| Network | Station Location | Tot. Daily Precip. (mm) |
|---|---|---|
| Weatherfarm | Arborg | 3.56 |
| | Balmoral | 87.12 |
| | Birds Hill – East St. Paul | 6.35 |
| | Broad Valley | 11.43 |
| | CWB Clouston Farms | 58.17 |
| | East Selkirk | 6.10 |
| | Fisher Branch | 3.30 |
| | Grosse Isle | 2.54 |
| | Inwood | 8.64 |
| | Kletke Seed Farm | 63.25 |
| | Lockport | 5.59 |
| | Meadows | 1.02 |
| | Rosser | 4.83 |
| | Selkirk | 5.59 |
| | St. Laurent | 12.45 |
| | Stonewall | 9.40 |
| | Winnipeg | 5.84 |
| MAFRI | Arborg | 3.05 |
| | Eriksdale | 19.30 |
| | Selkirk | 18.54 |
| | Teulon | 57.91 |
| | Woodlands | 10.67 |
| Environment Canada | Risher Branch | 4.90 |
| | Gimli | 0 |
| | Oak Point | No data |
| | Winnipeg Int'l Airport | 5.50 |

Table 6: Comparison of WeatherFarm, MAFRI and Environment Canada total daily precipitation amounts for June 13 Interlake rainfall event

A storm in the City of Winnipeg, May 29-30, 2010, can be used to further highlight the spatial variability of convective precipitation events, and the need for granular weather networks. In this event, 33 rain gauges (operated by the City of Winnipeg) recorded 31.8 to 107.4 mm in 28.5 hours. The spatial variability of this storm is significant and is highlighted by Figure 3. Precipitation amounts varied from 31 to over 100 mm within a distance of 10 to 12 km, highlighting the need for a dense weather network in the City of Winnipeg. The Environment Canada gauge operated at the airport is not used in this analysis as user specific start and end times (referred to as storm total) are required for waste and water management by the City. Based on the Environment Canada historical archive, 60.2 mm of precipitation fell over the entire day of May 29 (54.5 mm) and 30 (5.7 mm), while the City of Winnipeg period was defined as 7:30 am on May 29 and ended on May 30 and 12:00 noon.

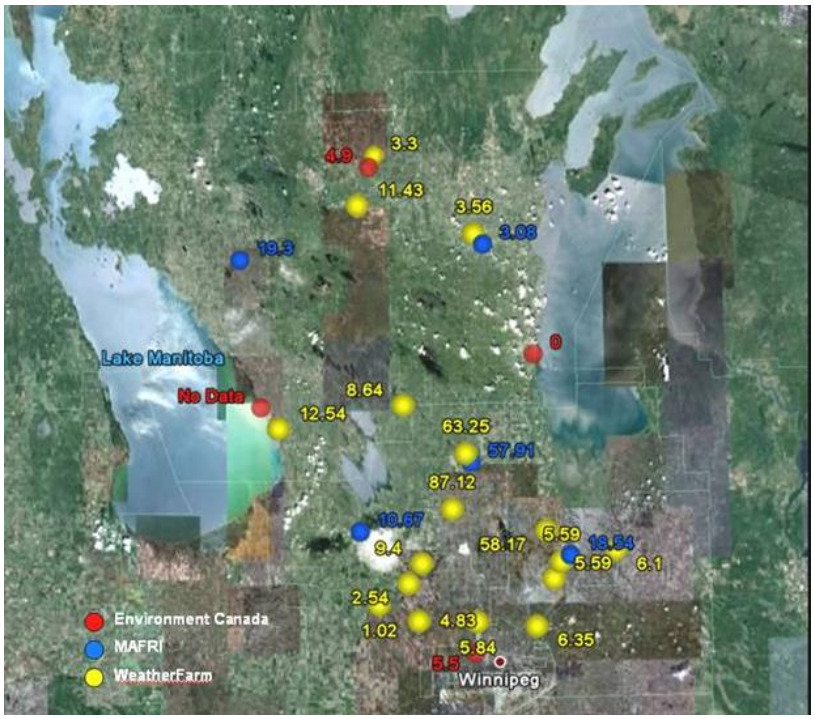



Figure 2: Spatial distribution of rainfall for June 13 Interlake event

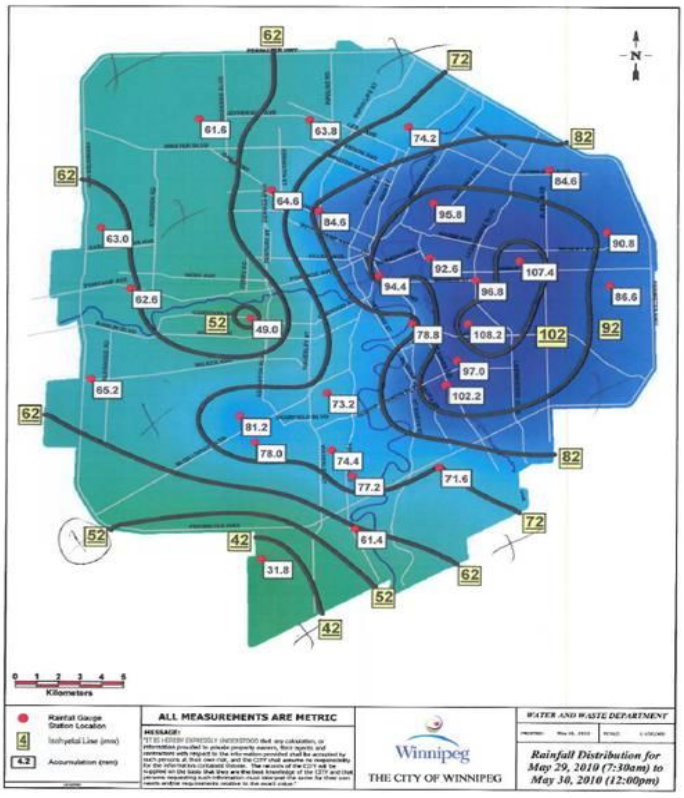
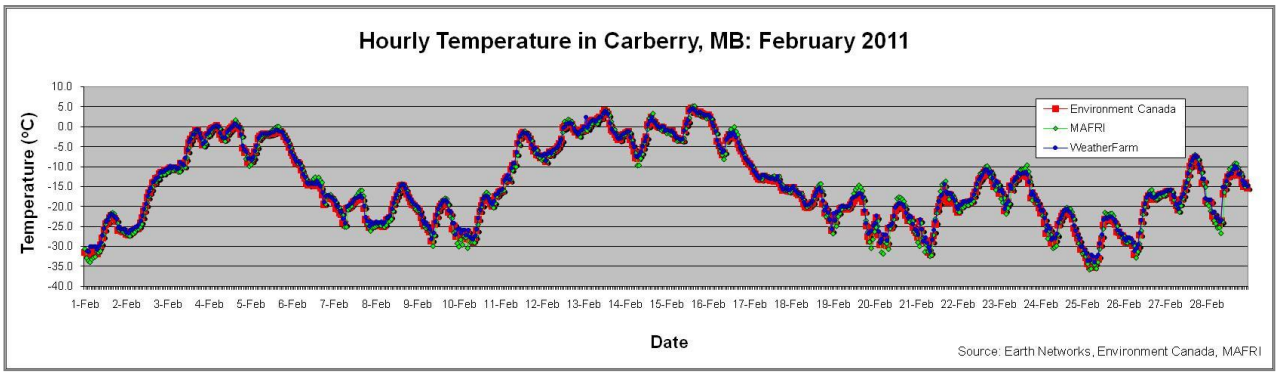



Figure 3: Distribution of rainfall for May 29 to 30, 2010 in the City of Winnipeg

## February 2011 Hourly Temperatures



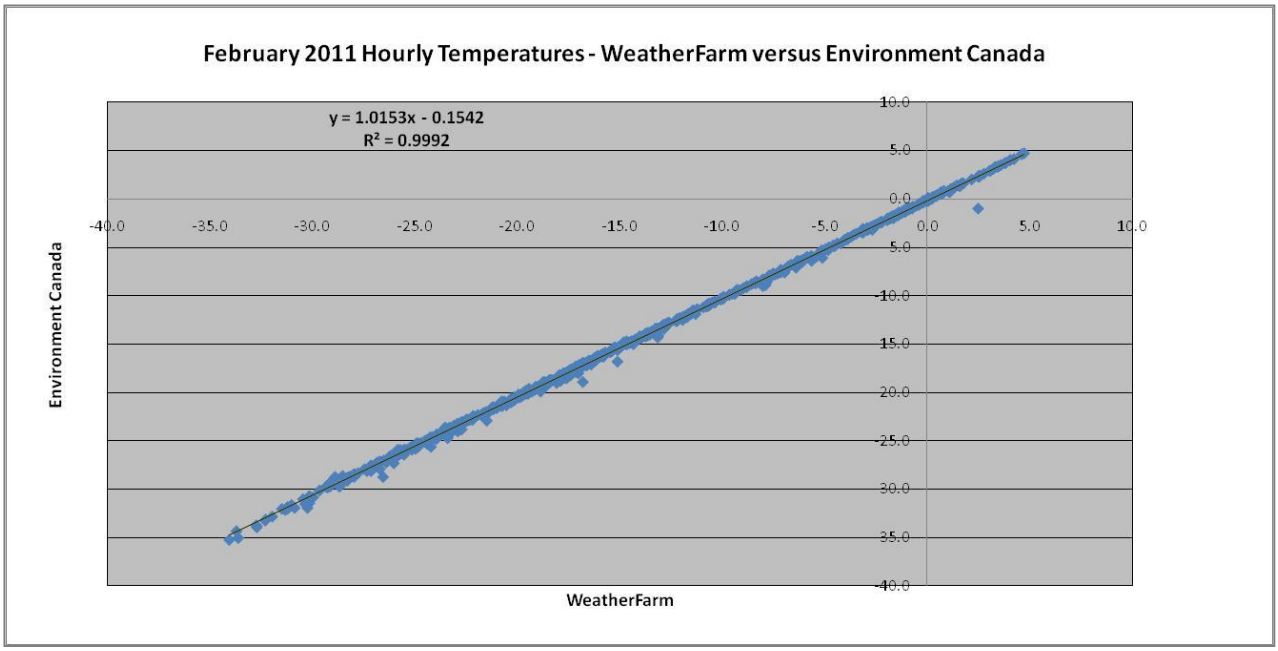

Graph 10: Comparison of Hourly Temperatures at Carberry, Manitoba: February 2011; sample size is 671 hourly observations

- The relative indices ($R^2$=0.9992 and d=0.9994) indicated that the predicted temperatures (WeatherFarm) were in very close agreement to the measured (Environment Canada) results.
- The RSME between the measured and predicted values is 0.47 $^{o}$C.
- The comparison of about 671 hourly observation for the month of May, the MAE error is 0.3727 $^{o}$C.
- The MBE value of 0.3713 $^{o}$C indicates that WeatherFarm is very slightly over estimating temperature.

| | |
|---|---|
| Average Difference | 0.3713 |
| $R^2$ | 0.9992 (0 to 1.0) |
| d | 0.9994 (0 to 1.0) |
| RMSE | 0.4736 (mm) |
| MAE | 0.3727 (mm) |
| MBE | 0.3713 (mm) |
| Paired T-test | 0.0000 |

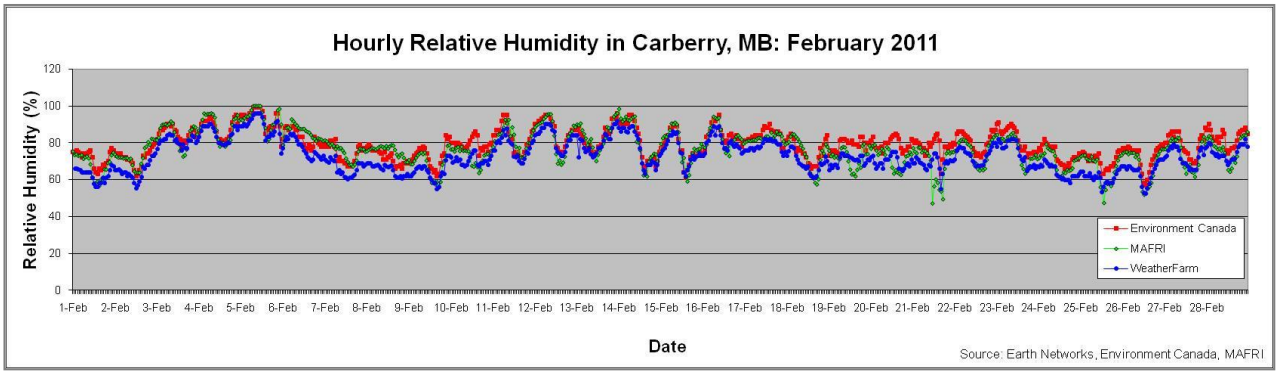
| | WeatherFarm | EC |
|---|---|---|
| Average | **-14.40** | **-14.80** |
| Standard Deviation | 9.5881 | 9.7428 |
| Standard Error Mean | 0.3701 | 0.3761 |
| Coefficient of Variance | -66.4614 | -65.8400 |

Table 7: Statistical analysis of the WeatherFarm versus Environment Canada February 2011 hourly temperatures at Carberry




Graph 11: Linear regression analysis of hourly WeatherFarm versus Environment Canada February 2011 temperatures

**February 2011 Hourly Relative Humidity**



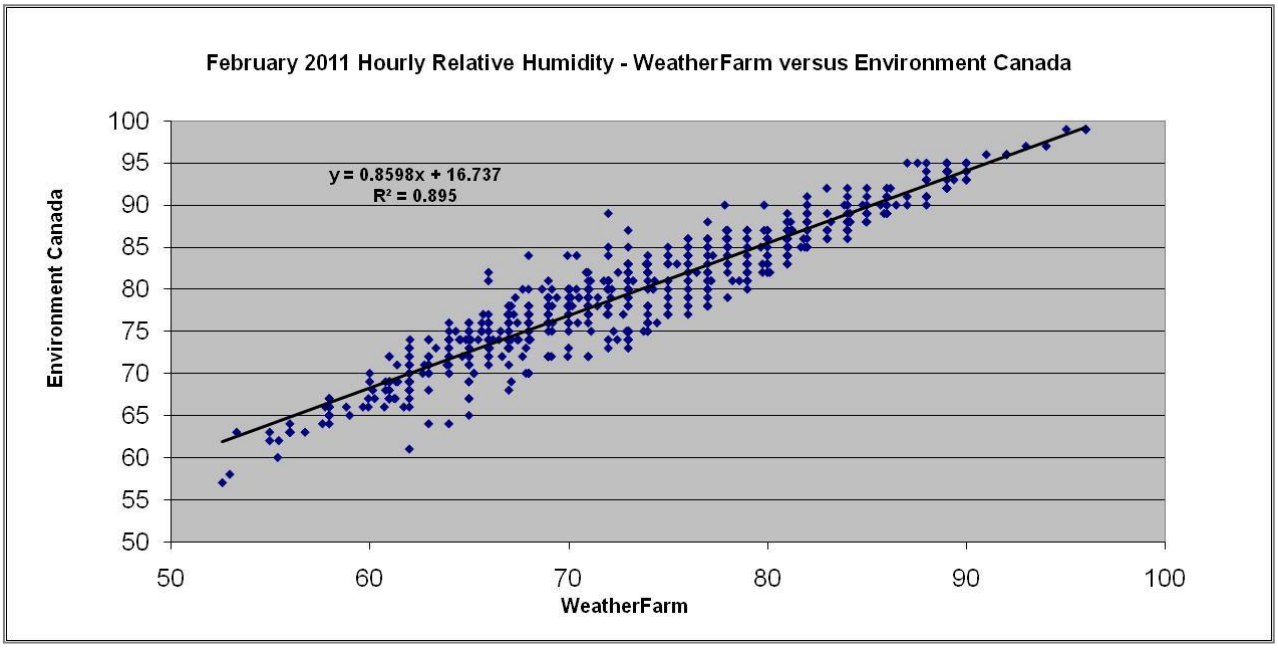

Graph 12: Comparison of Hourly Relative Humidity at Carberry, Manitoba: February 2011; sample size is approximately 671 observations

- The relative indices ($R^2$=0.895 and d=0.8422) indicated that the predicted relative humidity (WeatherFarm) values were in close agreement to the measured (Environment Canada) results.
- The RSME between the measured and predicted values is 7.12 %.
- For the comparison of about 671 hourly observations for the month of May, the MAE is 6.535 %.
- The MBE value of -6.532 % indicates that WeatherFarm is under estimating relative humidity.

| | |
|---|---|
| Average Difference | -6.5326 |
| $R^2$ | 0.8950 (0 to 1.0) |
| d | 0.8422 (0 to 1.0) |
| RMSE | 7.1206 (%) |
| MAE | 6.5356 (%) |
| MBE | -6.5356 (%) |
| Paired T-test | 0.0000 |

| | WeatherFarm | EC |
|---|---|---|
| Average | **72.79** | **79.33** |
| Standard Deviation | 8.6925 | 7.8944 |
| Standard Error Mean | 0.3356 | 0.3048 |
| Coefficient of Variance | 11.9412 | 9.9518 |

Table 8: Statistical analysis of the WeatherFarm versus Environment Canada February 2011 hourly relative humidity at Carberry




Graph 13: Linear regression analysis of hourly WeatherFarm versus Environment Canada May 2011 relative humidity percentages

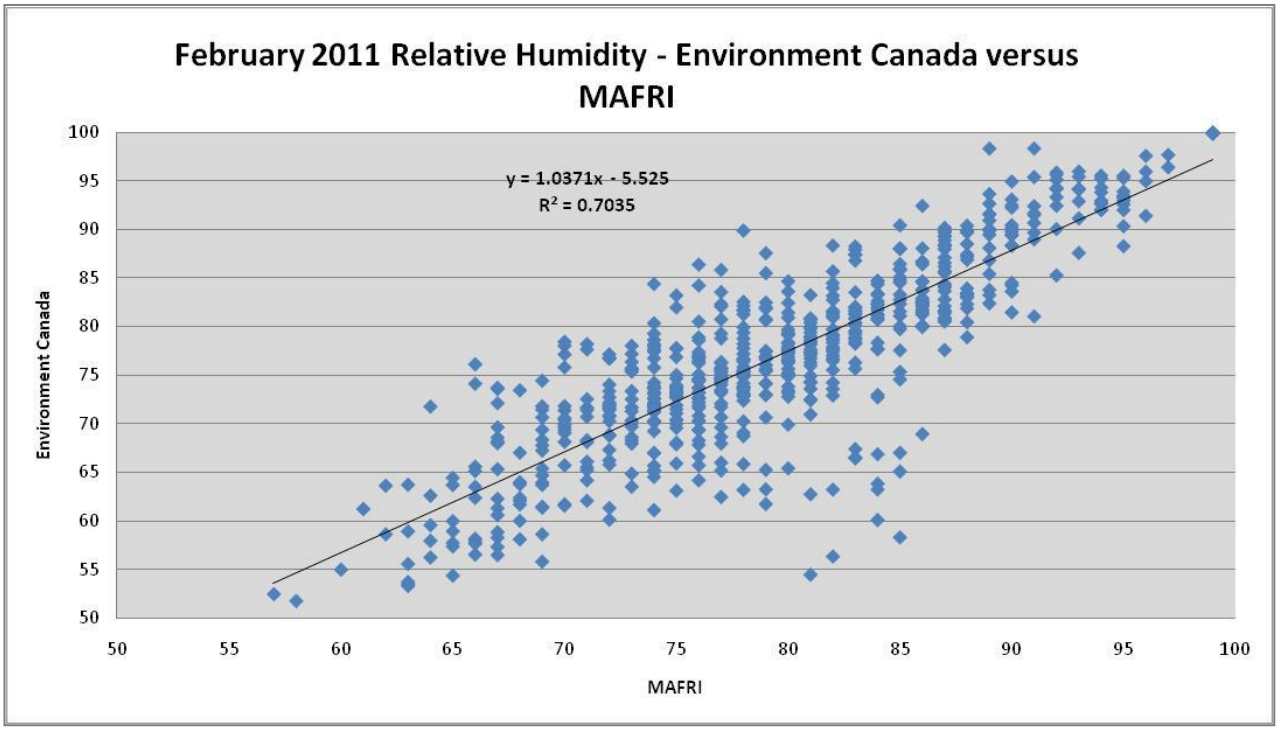
Since there was a larger variation between the WeatherFarm and Environment Canada hourly relative humidity readings for February 2011, the MAFRI and Environment Canada measurements were also analyzed. Note that the MAFRI relative humidity sensor is 30 cm above the ground or closer to moisture supply in winter months. These results also suggest a fair amount of variability exists between MAFRI and Environment Canada Measurements.

- The relative indices ($R^2$=0.7035 and d=0.8844) indicated that the predicted relative humidity (MAFRI) values were in close agreement to the measured (Environment Canada) results.
- The RSME between the measured and predicted values is 5.918 %.
- For the comparison of about 671 hourly observations for the month of May, the MAE error is 4.279%.
- The MBE value of -2.585 % indicates that MAFRI is under estimating relative humidity.

| | |
|---|---|
| Average Difference | -2.5856 |
| $R^2$ | 0.7035 (0 to 1.0) |
| d | 0.8845 (0 to 1.0) |
| RMSE | 5.9180 (%) |
| MAE | 4.2798 (%) |
| MBE | -2.5856 (%) |
| Paired T-test | 0.0000 |

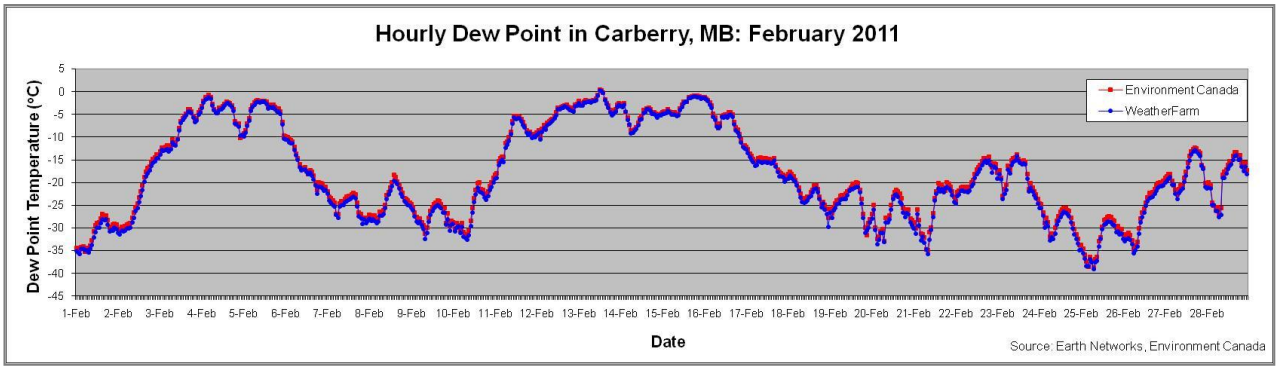
| | MAFRI | EC |
|---|---|---|
| Average | **72.79** | **79.33** |
| Standard Deviation | 9.7612 | 7.8961 |
| Standard Error Mean | 0.3768 | 0.3048 |
| Coefficient of Variance | 12.7200 | 9.9548 |

Table 9: Statistical analysis of the MAFRI versus Environment Canada February 2011 hourly relative humidity at Carberry




Graph 14: Linear regression analysis of hourly WeatherFarm versus Environment Canada February 2011 relative humidity percentages

## February 2010 Dew Point Temperatures



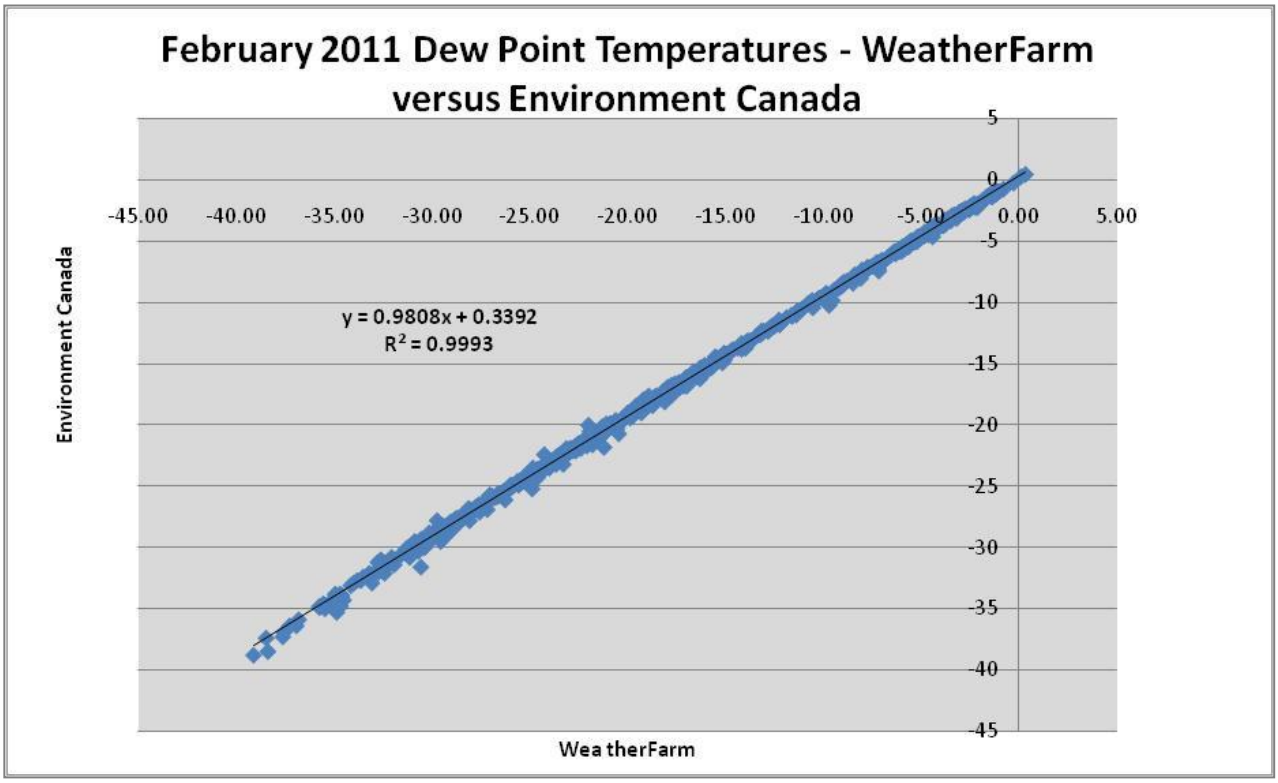

Graph 15: Comparison of Hourly Dew Point Temperatures at Carberry, Manitoba: February 2010; sample size is 671 observations

As expected, most relative humidity sensors have difficulty in measuring relative humidity at very cold temperatures thus a better measure of water vapor in winter months (February 2011) is conducted using dew point temperature sensors.

- The relative indices ($R^2$=0.9993 and d=0.9999) indicated that the predicted dew point temperature (WeatherFarm) values were in extremely close agreement to the measured (Environment Canada) results.
- The RSME between the measured and predicted values is 0.768 $^{o}$C.
- For the comparison of about 671 hourly observations for the month of February, the MAE is 0.702 $^{o}$C .
- The MBE value of -0.690 $^{o}$C indicates that WeatherFarm is very slightly under estimating dew point temperature.

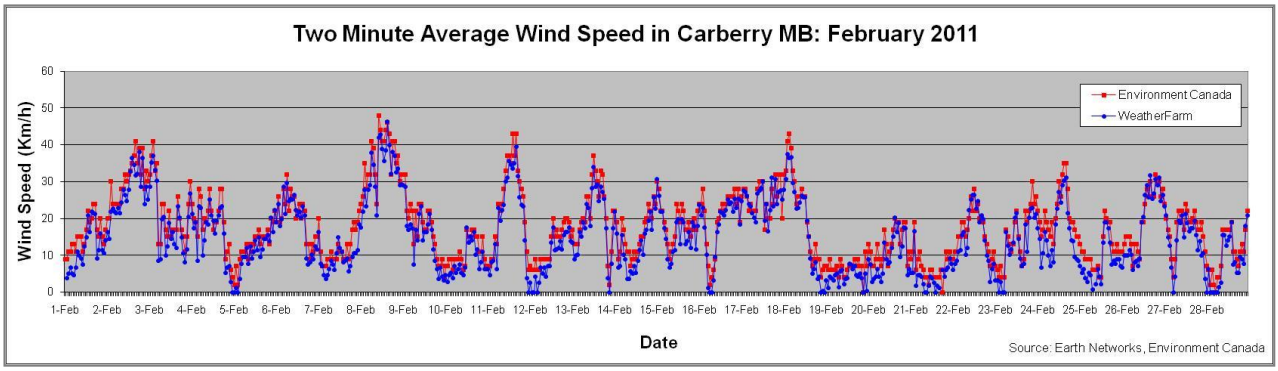
| | | |
|---|---|---|
| Average Difference | 0.6907 | |
| $R^2$ | 0.9993 (0 to 1.0) | |
| d | 0.9999 (0 to 1.0) | |
| RMSE | 0.7684 (C) | |
| MAE | 0.7025 (C) | |
| MBE | -0.6907 (C) | |
| Paired T-test | 0.0000 | |
| | **WeatherFarm** | **EC** |
| Average | **-18.29** | **-17.60** |
| Standard Deviation | 10.2030 | 10.0102 |
| Standard Error Mean | 0.3939 | 0.3864 |
| Coefficient of Variance | -55.7938 | -56.8883 |

Table 10: Statistical analysis of the WeatherFarm versus Environment Canada February 2011 hourly dew point temperatures at Carberry




Graph 16: Linear regression analysis of hourly WeatherFarm versus Environment Canada February 2011 dew point temperatures

**February 2011, Two-minute Average Wind Speed**




Graph 17: Comparison of Two-minute Average Wind Speed at Carberry, Manitoba: July 2010; sample size is 671 observations

As illustrated in Figure 1, WeatherFarm and Environment Canada anemometers are installed at different heights – about 3.4 meters for WeatherFarm and 10 meters for Environment Canada. This is an example of where the sensor installation height serves the intended application - agriculture. In urban settings, some WeatherFarm weather stations are installed on roof tops, which can provide better sites for laminar air flow and higher average wind speeds. Again these sites are serving the intended applications.

The WeatherFarm sensor installed at 3.4 meters will have an effect on the laminar airflow and be more prone to eddy fluxes from surface drag (slower wind speeds). In other words, this statistical comparison is not comparing “apples to apples”. Despite the differences in installation height, the correlations are still significant.

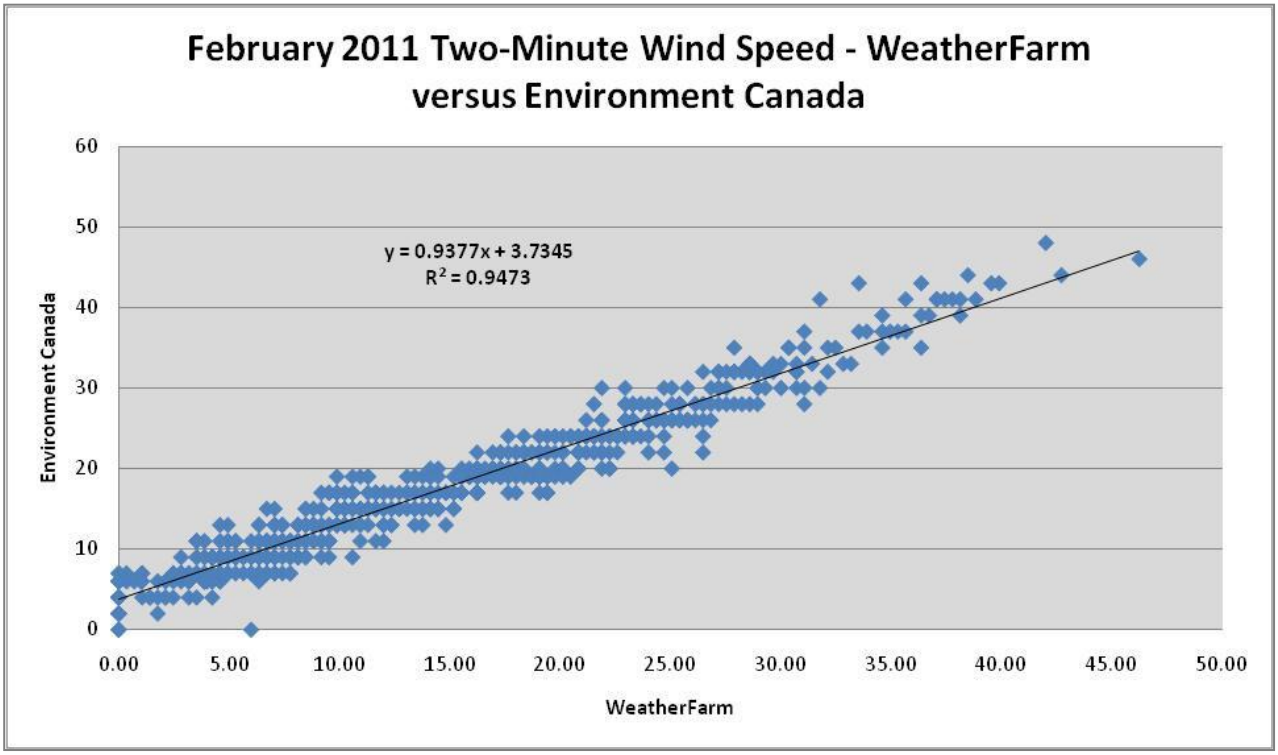
- The relative indices ($R^2$=0.9473 and d=0.9643) indicated that the predicted two-minute average wind speed (WeatherFarm) values were in close agreement to the measured (Environment Canada) results.

- The RSME between the measured and predicted values is 3.56 km/hr.
- For the comparison of 671 hourly observations for the month of February, the MAE is 3.014 km/hr.
- The MBE value of -2.808 km/hr indicates that WeatherFarm is slightly under estimating the two-minute wind speed.

| | |
|---|---|
| Average Difference | -2.8087 |
| $R^2$ | 0.9473 (0 to 1.0) |
| d | 0.9643 (0 to 1.0) |
| RMSE | 3.5623 (km/Hr) |
| MAE | 3.0144 (km/Hr) |
| MBE | -2.8087 (km/Hr) |
| Paired T-test | 0.0000 |

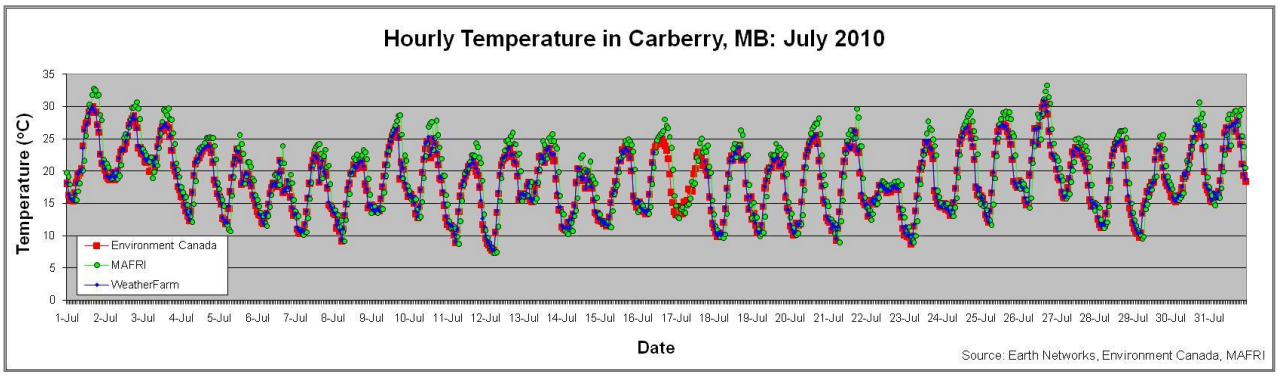
| | WeatherFarm | EC |
|---|---|---|
| Average | **14.86** | **17.67** |
| Standard Deviation | 9.5472 | 9.1980 |
| Standard Error Mean | 0.3686 | 0.3551 |
| Coefficient of Variance | 64.2327 | 52.0479 |

Table 11: Statistical analysis of the WeatherFarm versus Environment Canada February 2011 two-minute average wind speed at Carberry




Graph 18: Linear regression analysis of WeatherFarm versus Environment Canada, February 2011 two-minute average wind speed

## July 2010 Hourly Temperatures

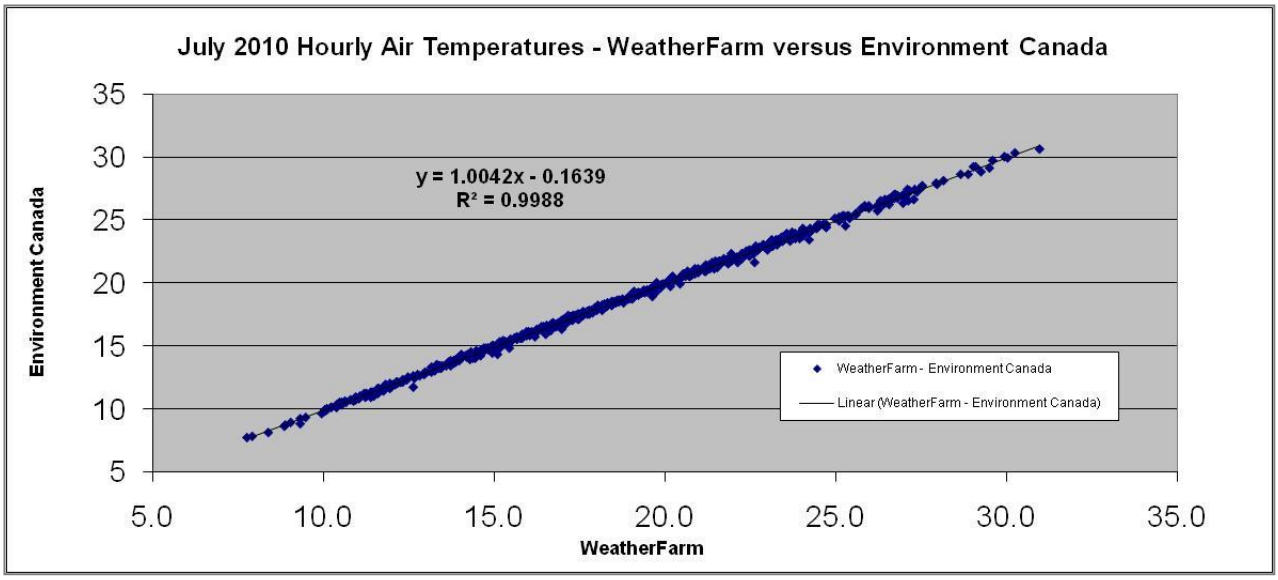



Graph 19: Comparison of Hourly Temperatures at Carberry, Manitoba: July 2010; sample size is 703 observations. WeatherFarm is missing data on July 17 and 18.

- The relative indices ($R^2$=0.9988 and d=0.9996) indicated that the predicted temperatures (WeatherFarm) were in very close agreement to the measured (Environment Canada) results.
- The RSME between the measured and predicted values is 0.1906 $^{o}$C.
- The comparison of about 701 hourly observation for the month of July, the MAE error is 0.1377 $^{o}$C.
- The MBE value of 0.0848 $^{o}$C indicates that WeatherFarm is very slightly over estimating temperature.

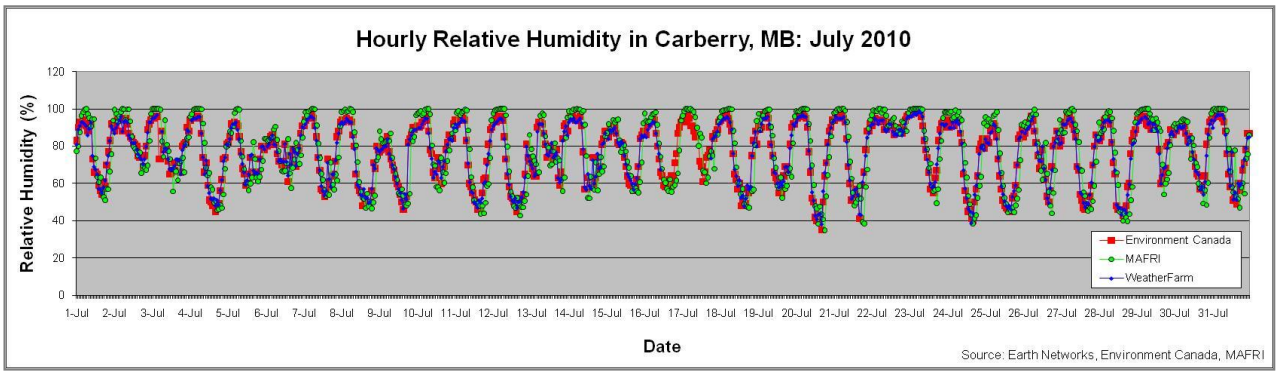
| | | |
|---|---|---|
| Average Difference | 0.0848 | |
| $R^2$ | 0.9988 (0 to 1.0) | |
| d | 0.9996 (0 to 1.0) | |
| RMSE | 0.1906 (C) | |
| MAE | 0.1377 (C) | |
| MBE | 0.0848 (C) | |
| Paired T-test | 0.0000 | |
| | **WeatherFarm** | **EC** |
| Average | **18.68** | **18.59** |
| Standard Deviation | 4.8699 | 4.8934 |
| Standard Error Mean | 0.1839 | 0.1848 |
| Coefficient of Variance | 26.0703 | 26.3158 |

Table 12: Statistical analysis of the WeatherFarm versus Environment Canada July 2010 hourly temperatures at Carberry




Graph 20: Linear regression analysis of hourly WeatherFarm versus Environment Canada, July 2010 temperatures

**July 2010 Hourly Relative Humidity**



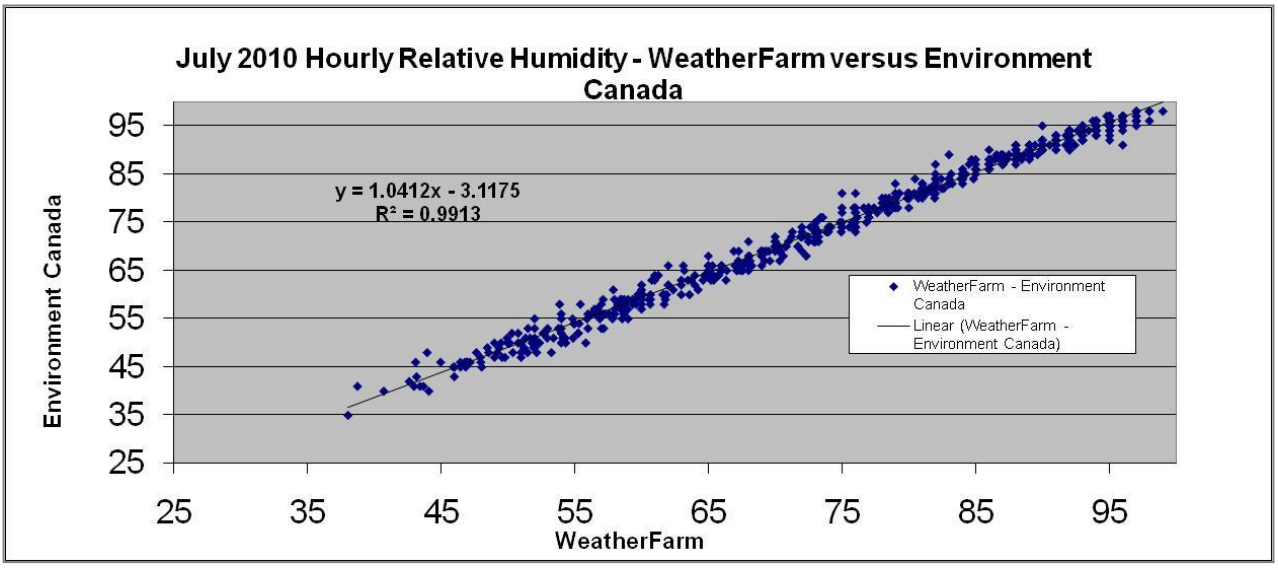

Graph 21: Comparison of Hourly Relative Humidity at Carberry, Manitoba: July 2010; sample size is 703 observations. WeatherFarm is missing data on July 17 and 18.

- The relative indices ($R^2$=0.9913 and d=0.9973) indicated that the predicted relative humidity (WeatherFarm) values were in very close agreement to the measured (Environment Canada) results.
- The RSME between the measured and predicted values is 1.6188 %.
- For the comparison of about 701 hourly observations for the month of July, the MAE is 1.2245 %.
- The MBE value of -0.0453 % indicates that WeatherFarm is very slightly under estimating relative humidity.

| | |
|---|---|
| Average Difference | -0.0453 |
| $R^2$ | 0.9913 (0 to 1.0) |
| d | 0.9973 (0 to 1.0) |
| RMSE | 1.6188 (%) |
| MAE | 1.2245 (%) |
| MBE | -0.0453 (%) |
| Paired T-test | 0.0000 |

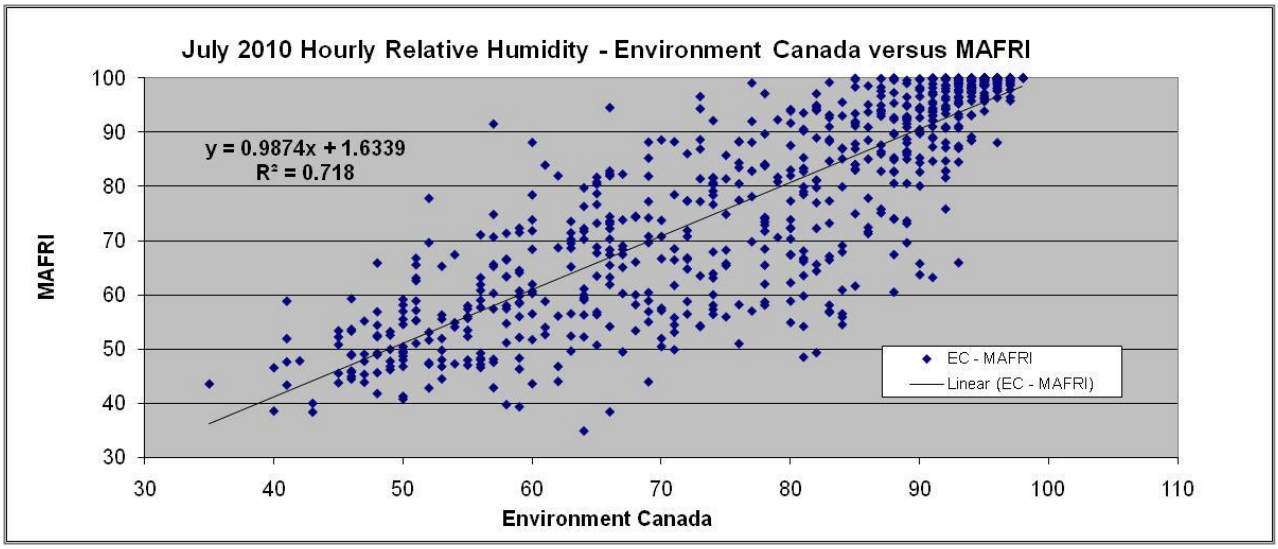
| | WeatherFarm | EC |
|---|---|---|
| Average | **76.84** | **76.88** |
| Standard Deviation | 15.2758 | 15.9744 |
| Standard Error Mean | 0.5770 | 0.6033 |
| Coefficient of Variance | 19.8802 | 20.7772 |

Table 13: Statistical analysis of the WeatherFarm versus Environment Canada July 2010 hourly relative humidity at Carberry.

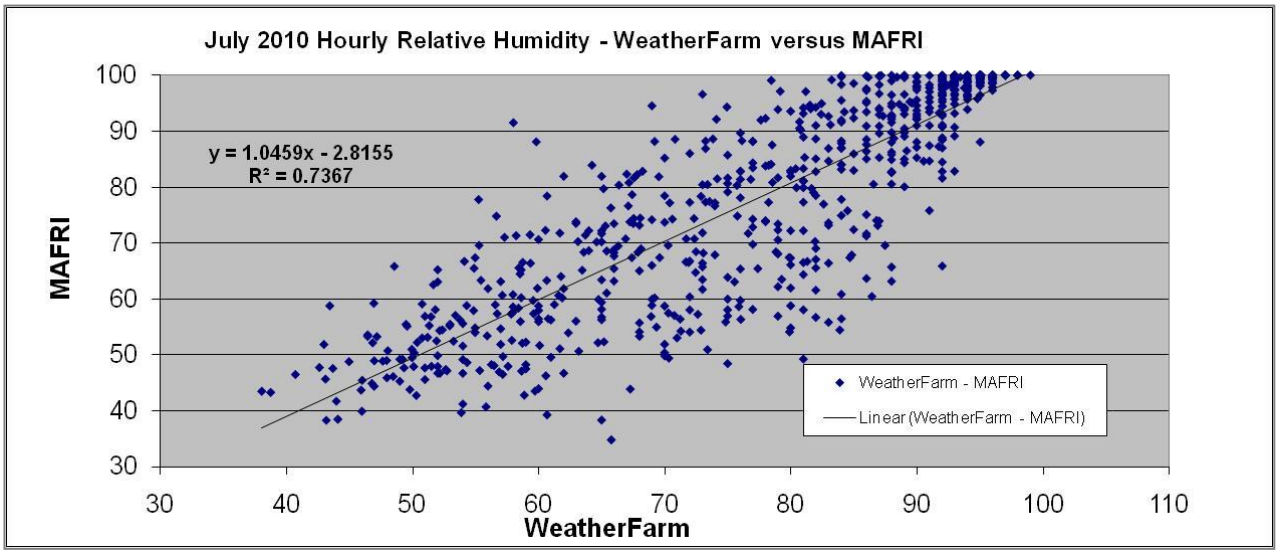



Graph 22: Linear regression analysis of hourly WeatherFarm versus Environment Canada, July 2010 relative humidity percentages

The next two regression graphs are included to illustrate the relationships between relative humidity at the three weather stations and the effect of none standardized sensor height on observed values. In this case, the MAFRI relativity sensor serves a direct purpose, to monitor humidity conditions near the canopy of a potato crop for calculating a disease index. This illustrates that the data is not bad, but serves the intended application.



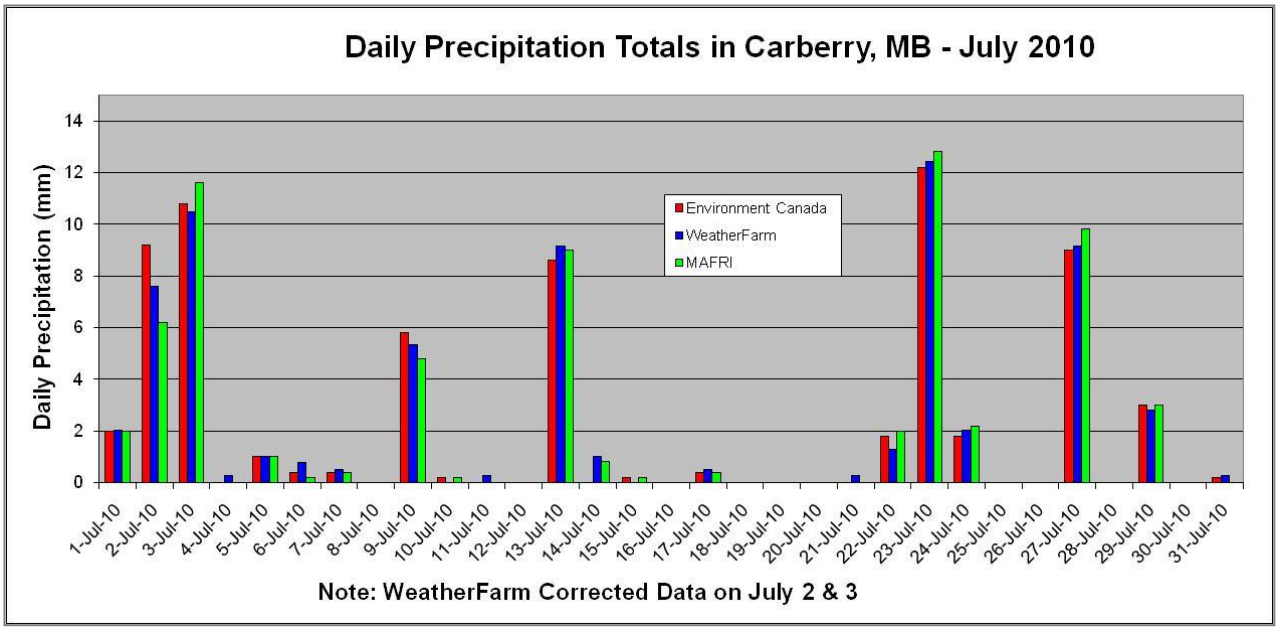

Graph 23: Linear regression analysis of hourly WeatherFarm versus Environment Canada, July 2010 relative humidity percentages




Graph 24: Linear regression analysis of hourly WeatherFarm versus Environment Canada, July 2010 relative humidity percentages

### July 2010 Daily Precipitation

Note**:** It was not possible to undertake hourly analysis as daily values were only available from Environment Canada. WeatherFarm data for July 2 and 3 was adjusted as the rainfall measurement captured just before midnight was placed into the next day. This error has since been corrected in WeatherFarm.



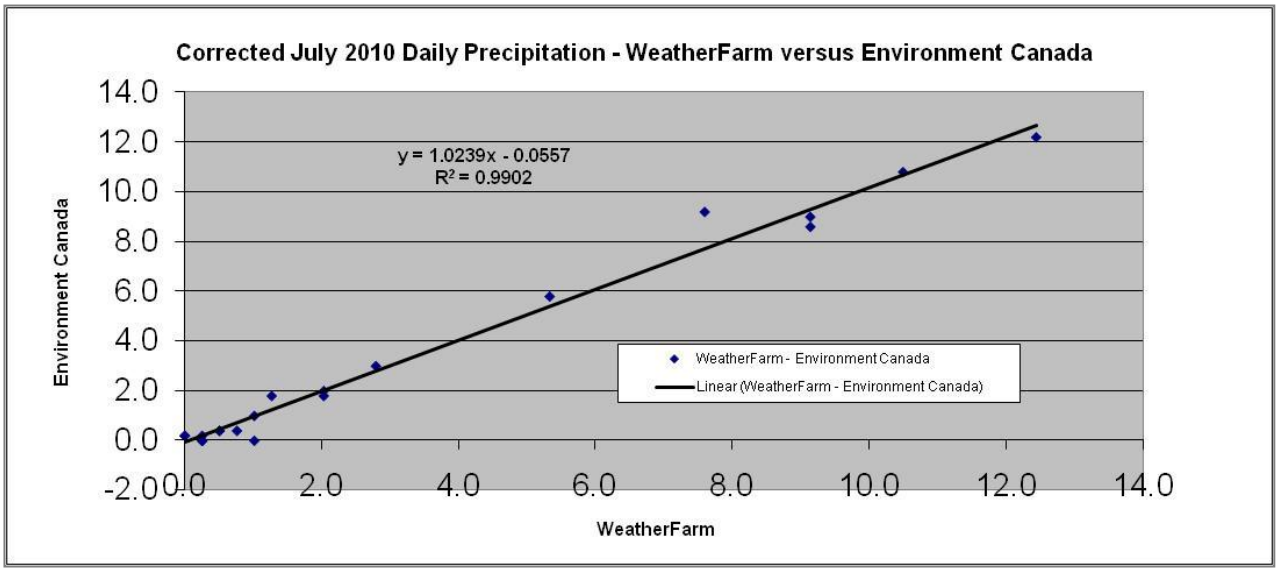

Graph 25: Comparison of daily precipitation measurements at Carberry, Manitoba: July 2010

- The relative indices ($R^2$=0.9902 and d=0.9956) indicated that the predicted daily precipitation (WeatherFarm) values were in very close agreement to the measured (Environment Canada) observation.
- The RSME between the measured and predicted values is 0.4921 mm.
- For the comparison of 21 daily observations for the month of July, the MAE error is 0.3393 mm.
- The MBE value of 0.0058 mm indicates that WeatherFarm is minimally over estimating precipitation according to the Environment Canada site at Carberry. **It should be noted that precipitation varies greatly over short distances and therefore, as expected, no two rain gauges will have exactly the same readings.**

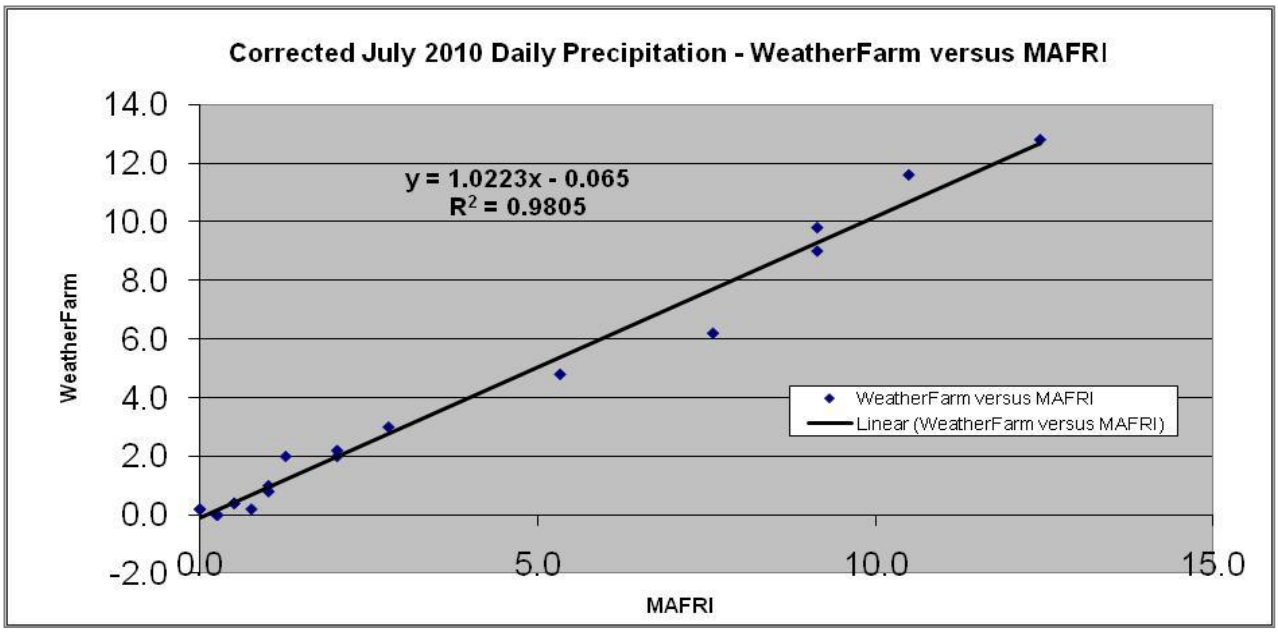
| | |
|---|---|
| Average Difference | 0.0058 |
| $R^2$ | 0.9902 (0 to 1.0) |
| d | 0.9956 (0 to 1.0) |
| RMSE | 0.4921 (mm) |
| MAE | 0.3393 (mm) |
| MBE | 0.0058 (mm) |
| Paired T-test | 0.0000 |

| | WeatherFarm | EC |
|---|---|---|
| Average | **3.20** | **3.19** |
| Standard Deviation | 4.1596 | 4.1596 |
| Standard Error Mean | 0.9077 | 0.9077 |
| Coefficient of Variance | 130.1372 | 130.3741 |

Table 14: Statistical analysis of the WeatherFarm versus Environment Canada July 2010 daily precipitation at Carberry




Graph 26: Linear regression analysis of daily WeatherFarm versus Environment Canada, July 2010 precipitation values




Graph 27: Linear regression analysis of daily WeatherFarm versus MAFRI, July 2010 precipitation values

### *Summary and Conclusions*

The statistical results based on actual sensors comparisons at Carberry, Manitoba for hundreds of hourly observations for the month of May and February, 2011 and July, 2010 clearly illustrate that there is little statistical difference in the measured (Environment Canada) versus predicted values (WeatherFarm) for temperature, dew point, precipitation and in most cases relative humidity.

Wind speed for February 2011 was also analyzed and found to have a significant correlation to Environment Canada anemometers, despite the two sensors are installed at different heights (3.4 meters for WeatherFarm and 10 meters for Environment Canada). Relative humidity correlations for February 2011 were less than in summer months, but this was attributed to the sensitivity of these sensors at very cold temperatures. To further assess water vapour in winter months, dew point temperatures were statistically compared and were found to be significantly correlated.

Precipitation measurements for the liquid season were compared to both MAFRI and Environment Canada gauges and were found to be significantly correlated in all cases. There was little statistical difference in tipping buckets to weighing gauge measurements. Tipping bucket gauges were also examined under an extreme rainfall event on June 17, 2011 in southern Saskatchewan (10 to 110+ mm). The tipping buckets in all but one case (6 out of 7 sites) measured more (1.7 to 23.8 mm) than the Environment Canada gauges, which demonstrated that tipping bucket gauges do not under estimate in heavy rainfall events. A further benefit of the WeatherFarm network during this storm demonstrated the need for highly granular geographic data to capture localized convection precipitation events.

This study has demonstrated that WeatherFarm sensors are complementary to Environment Canada stations and that the granularity (geographically and temporally) of the data has significant advantages for real-time management and decision making for flood prediction, monitoring, and forecasting. The data has also been used to increase the timeliness and accuracy of Watch, Warnings and Special Weather Statements issued by Environment Canada.