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Field Measurements of Temperature Sensitivity in Geonor Vibrating-Wire Transducers

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1. INTRODUCTION

The primary instrument for measuring precipitation in the United States Climate Reference Network (USCRN) is the Geonor vibrating-wire weighing-bucket all-weather precipitation gauge. A gauge can have 1 to 3 vibrating-wire transducers, each transducer producing an audio frequency in proportion to the accumulated mass (mixture of water, antifreeze, and oil) in the bucket. For a fixed mass in the bucket, the audio frequency recorded by each transducer changes in response to the temperature of and, perhaps, temperature gradient across the transducer housing. The temperature coefficient is negative, i.e., an increase in ambient temperature yields a decrease in frequency or apparent accumulation.

The purpose of this paper is to provide estimates of the temperature coefficient as a function of the accumulated precipitation in the bucket derived from field measurements. The dependence of temperature coefficient on temperature of the vibrating-wire transducer is also investigated.

2. FIELD SITE

The field site is located on the north campus of the University of Oklahoma in north Norman between the Oklahoma Mesonet Norman site and the National Severe Storms Laboratory. The Geonor precipitation gauge used in this study is in a 1.8 m x 3.7 m (6 ft x 12 ft) pit such that the rim of the gauge orifice is about 1 cm above the surrounding raindrop splash-prevention fabric.

3. DATA COLLECTION AND ANALYSIS

Beginning January 2003, daily measurements of 1-minute accumulations of precipitation from each of the three vibrating-wires and their average have been recorded. One-minute wind speed and wind direction at 2-m and the air temperature inside the gauge housing near the bucket also have been recorded.

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2. CONCEPT OF FIELD MEASUREMENT OF TEMPERATURE COEFFICIENT

On a clear day with no weather disturbance, the daily cycle of air temperature in the surface layer has an approximate sinusoidal shape such that two temperatures separated by 24 hours usually differ by less than a few degrees C. When this occurs and when the daily range is about 5 C or greater, a plot of the accumulation in the bucket versus temperature provides the data to which simple linear regression yields the temperature coefficient. An example of a "good" daily cycle of temperature is shown in Fig. 1. The temperature

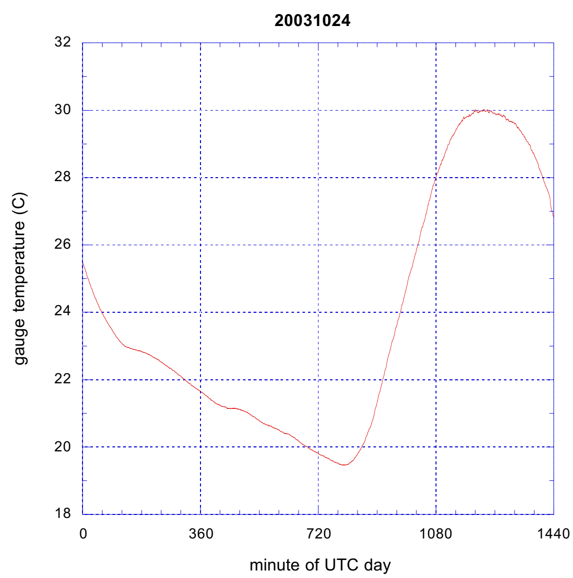

Fig. 1. An example of a desired daily cycle of temperature.

range is over 10 degrees and the difference between the temperatures at the beginning and end of the 24-hour period is less than 2 C. Fig. 2 shows the associated variation in accumulation versus gauge temperature. The direction of the curve is clockwise as determined by the location of the initial and final temperatures of the 24-hour period. That the curve is a loop (or nearly so) is because the temperature of a transducer, which is the main source of the accumulation variation, lags the gauge temperature. The greater the rate-of-change of gauge temperature, the wider the loop.

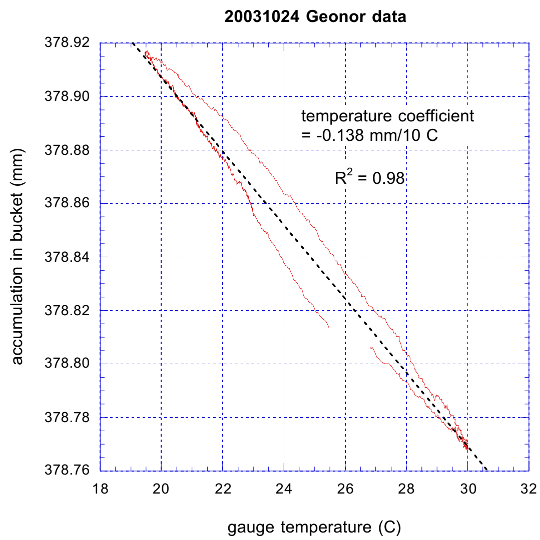

Fig. 2. Accumulation versus temperature inside the gauge.

The dashed line in Fig. 2 is a minimum least-squares (mls) linear-fit to the curved line and its slope is the temperature coefficient, the value of which, for this day, is –0.138 mm/10 C (-0.00543 in/10 C). The linear-fit explains 98% of the variance in the curved line. For this day the apparent accumulation in the bucket varied by 0.145 mm (0.00571 in) while the difference between the beginning and end of the day was about 0.01 mm (0.0004 in).

The regression line in Fig. 2 is derived from the average accumulation of the 3 vibrating-wires in the gauge. That is, the vertical axis is the average accumulation in the bucket. Daily calculations of the temperature coefficient are performed for each of the three wires as well as for their average. The temperature coefficient of one wire can be twice that of another wire. In this paper only the temperature coefficient for the average accumulation is given because, in practice, the average (or median) accumulation of the 3 wires is used to determine precipitation. In addition to systematic differences among the temperature coefficients of individual wires, they also exhibit more day-to-day variability than the temperature coefficient obtained from the average 1-minute accumulations. It is believed that the primary reason for the day-to-day variability is a non-uniform distribution of temperature within the gauge housing. Because the interior of the collection cylinder is black, it is a good absorber of solar radiation resulting in warm north side of the cylinder relative to south side in daytime. Differential expansion of the frame from which the bucket is suspended and differential expansion of the bucket itself can lead to a non-uniform distribution of mass in the bucket. An additional complication is the systematic variation of solar elevation and azimuth angles during the course of a day. Because there is only one temperature sensor, its temperature may not be representative of the temperature to which each transducer is responding. Using the average accumulation of the 3 wires reduces the differences among wires and provides an estimate of the temperature coefficient for the average accumulation that is stable and in which there is high confidence based on the R^2 statistic.

3. DETERMINATION OF DEPENDENCE OF THE TEMPERATURE COEFFICIENT ON ACCUMULATION IN THE BUCKET

While Fig. 2 clearly shows that the temperature coefficient is negative, it is equally important to determine whether it is dependent on accumulation in the bucket and, if so, the magnitude of this dependence, and the similar consideration for its dependence on temperature.

The answers to these questions are based on analysis of the data that were collected beginning January 2003 and continuing to late October, the time of writing, but data collection and analysis continue.

The accumulation data have been divided into 4 time periods as described below.

<u>Period 1: 17 January – 23 March 2003</u>

The project began and continued until a new data logger was installed, all new wiring was installed with improved electrical shielding along with better electrical grounding. During this period there were numerous cases of what was believed to be radio interference, perhaps from the not-too-distant regional airport, that disturbed the recorded frequencies from the vibrating-wires. During this period considerable effort was taken to remove the noise from the frequency time series produced by the vibrating-wires. The interference problem was not present in the next three periods.

Period 2: 12 May – 10 June 2003

In Period 2 the sampling scheme was to have the data logger measure the time required to accumulate 3000 cycles from each wire for each contiguous 10-second interval. The 1-minute average frequency for each wire was obtained by averaging the six 10-second averages. The result was very smooth 1-minute accumulations from which it was suitable to calculate 1-minute rain rates, as described by Duchon (2004). In contrast, in Period 1 a number of sampling schemes were used, ranging from 3000 cycles down to 50 cycles, the latter averaged over an appropriately shorter time interval. Period 2 ended when one of the 3 wires broke.

Period 3: 23 June – 26 August 2003

This period began with the installation of the new vibrating-wire to replace the vibrating-wire that broke and ended with a long dry period with mean daily temperatures above 30 C.

Period 4: 2 September – 22 October 2003

Significantly cooler mean daily temperatures than in August along with precipitation mark the beginning of this period. The end of the period occurred with the last data used in this paper.

Fig. 3 shows daily values of the temperature coefficient from January to October and color-coded according to period. The upper part of the figure shows the associated temperature ranges and the number of days in each period. The data have been screened such that only days with a gauge temperature $\geq$ 5.0 C and $R^2 \geq 0.90$ are shown (and analyzed). It should be noted that values of temperature coefficient begin at an accumulation around 80 mm. The 80 mm amount is the result of adding antifreeze to prevent freezing and mineral oil to prevent evaporation. There is no water in the bucket.

Fig. 3 clearly shows there is an increase in the magnitude of the temperature coefficient with accumulation in the bucket. The cluster of values from the Period 1 appears to be displaced downward from the trend indicated by the remaining 3 periods. There is no obvious reason for the displacement.

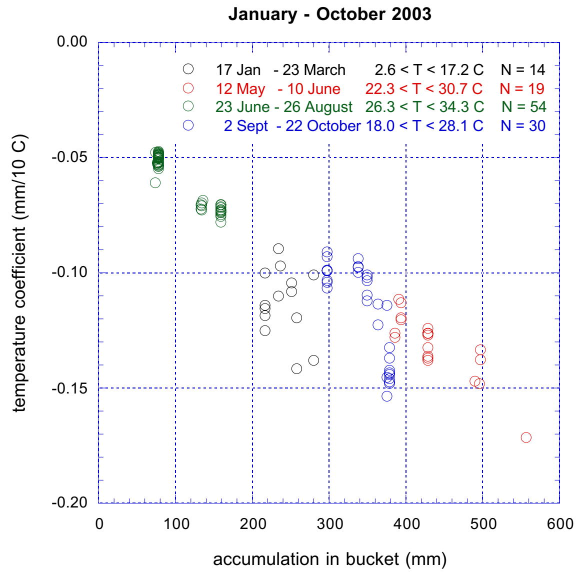

Fig. 3 Dependence of temperature coefficient on accumulation

In Fig. 4 a mls linear-fit has been applied to the data in Fig. 3 without reference to period.

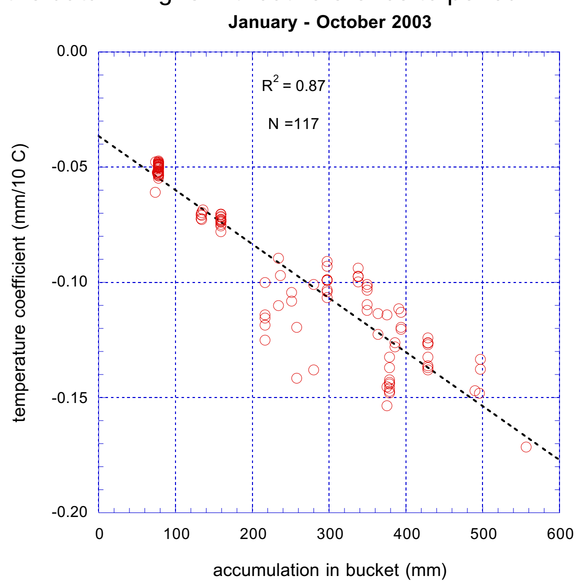

Fig. 4 A minimum least-squares linear-fit to the data in Fig.3.

For the range in accumulation from about 80 to 550 mm the magnitude of the temperature coefficient increases by more than a factor of 3. With the removal of the data from Period 1, Fig. 5 shows that the value of R^2 is now 0.93 compared to 0.87 in Fig. 4, but the slope is nearly the same.

The obvious conclusion from Figs. 4 and 5 is that the influence of temperature on precipitation estimation can be reduced by keeping the accumulated precipitation in the bucket as low as possible. Whether or not this is practical depends on the resources available for an indvidual to remove the accumulated precipitation, particularly in a high precipitation environment.

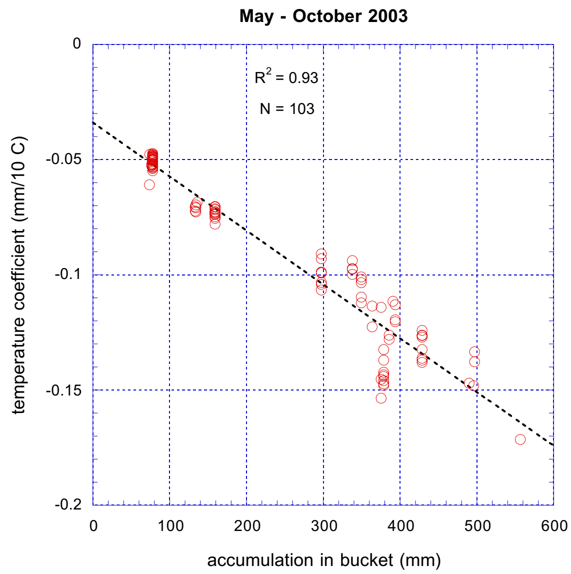

Fig. 5 A minimum least-squares linear-fit to the data in Fig.3 without Period 1.

4. DETERMINATION OF DEPENDENCE OF THE TEMPERATURE COEFFICIENT ON TEMPERATURE

As expected, the colder temperatures among the four periods occurred during Period 1. As noted in the section 3, the distribution of temperature coefficients in Period 1 seemed to be displaced toward a higher magnitude relative to the straight-line defined by Periods 2-4. Fig. 6 shows the temperature coefficients for Period 1 only and includes the mean daily temperature posted to the upper-right (where possible) of each temperature coefficient. The conclusion is the opposite of what one might have expected. That is, Fig. 6 suggests the higher the gauge temperature, the greater the magnitude.

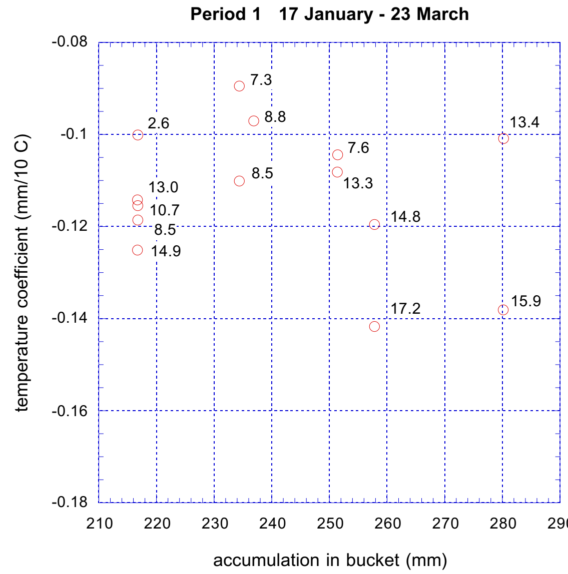

Fig. 6 Expanded view of the temperature coefficients for Period 1 including the associated mean daily temperature.

Another way to examine the possible dependence of the temperature coefficient on gauge temperature is to plot daily temperature coefficients during periods of no rain. For this purpose 5 periods are available ranging in length from 8 to 29 consecutive days. The temperature coefficients are shown in Figs. 7 to 11. In each figure the range of the horizontal temperature axis is 10 C and the vertical axis 0.02 mm/10 C.

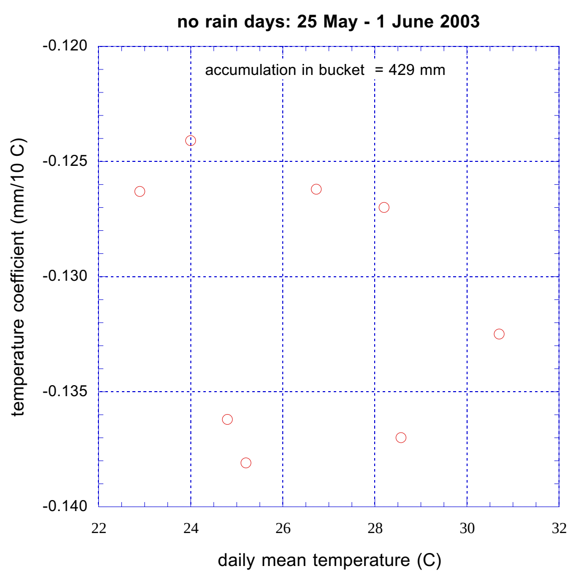

Fig. 7 Temperature coefficients for 8 consecutive days with no rain.

Although the temperature coefficients are for only 8 days of no rain in Fig. 7, there is no evidence for their dependence on temperature. Fig. 8 has the longest no rain period, 29 days, again, without any apparent temperature dependence. The range in accumulation among the 5 periods is 78 to 429 mm, Fig. 8 having the lowest.

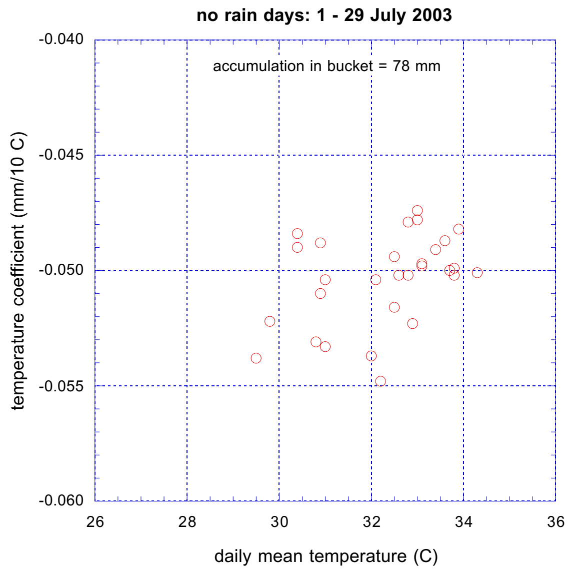

Fig. 8 Temperature coefficients for 29 consecutive days with no rain.

Neither Fig. 9 nor Fig. 10 show evidence for the temperature coefficient dependent on temperature. On the other hand, Fig. 11, with 8

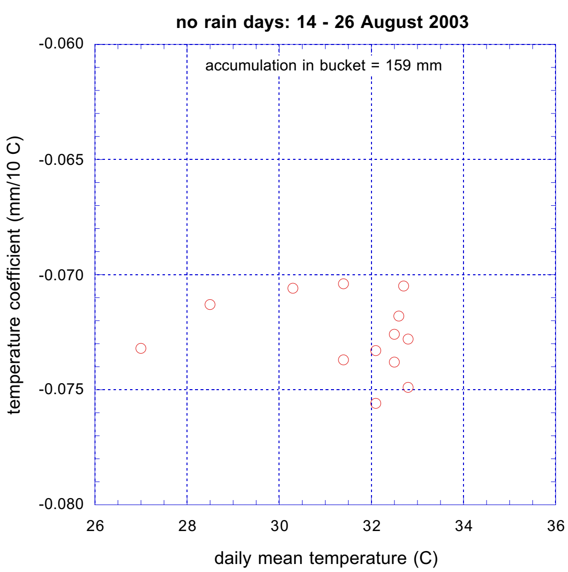

Fig. 9 Temperature coefficients for 13 consecutive days with no rain.

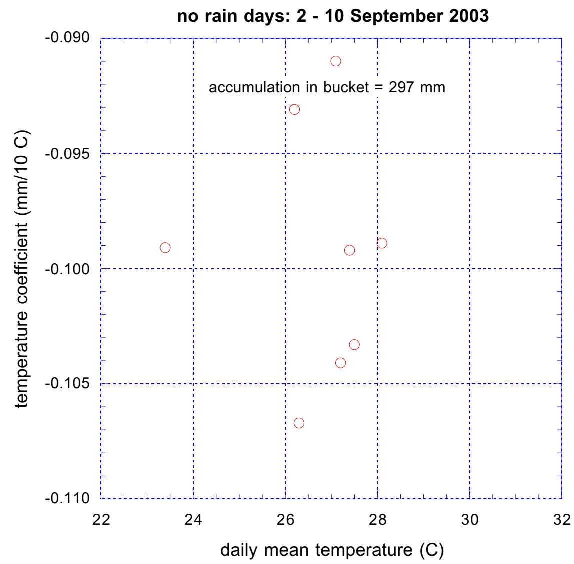

Fig. 10 Temperature coefficients for 8 of 9 consecutive days with no rain.

days, does suggest an increase in magnitude with an increase in temperature, in agreement with Fig. 6. However, the temperature coefficients for 23 – 25 October (not shown) add to the scatter of points and do not support a temperature dependence.

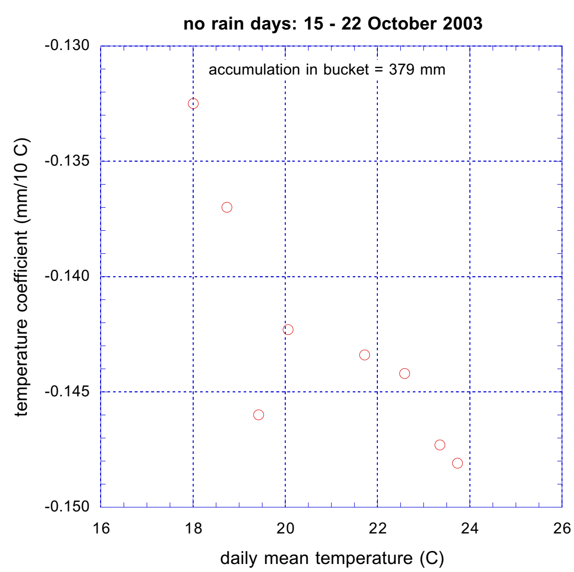

Fig. 11 Temperature coefficients for 8 consecutive days with no rain.

5. SUMMARY AND CONCLUSIONS

Beginning January 2003, accumulation data from a 3-wire Geonor all-weather precipitation gauge were collected and analyzed, one goal of which was to determine the dependence of the temperature coefficient of vibrating-wire transducers on accumulated precipitation in the bucket and on gauge temperature. The gauge was located in a pit such that the rim of the collector was at approximately ground level.

The basis for determining the temperature coefficient was response of the transducer to the daily cycle of gauge temperature. Clear days with no weather disturbance provided optimal conditions for estimating the temperature coefficient. The procedure was to plot the accumulation in the bucket versus gauge temperature for each day and use linear regression to fit a straight-line to the data. The slope of the line is the temperature coefficient. Each wire has its own temperature coefficient. The temperature coefficients given in this paper are derived from the average accumulation versus temperature because they are more stable than the temperature coefficients of individual vibrating-wires

The results show that the temperature coefficient is quite dependent on accumulation in the bucket, ranging from about –0.05 mm/10 C (–0.002 in/10 C) at 80 mm, the lowest available accumulation, to about –0.17 mm/10 C (–0.007 in/10 C) at 550 mm. The conclusion is that the accumulation in the bucket should be kept low to minimize the temperature effect. Based on consecutive days of no rain, the analysis to date indicates that if the temperature coefficient is dependent on temperature, it is much less important than its dependence on accumulation in the bucket. Additional field data should provide a more definitive answer to the question of temperature dependence.

6. ACKNOWLEDGEMENTS

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7. REFERENCE

Duchon, C. E., 2004: Observations of 1-minute rain rates using a vibrating-wire weighing-bucket rain gauge. 14th Conf. on Appl. Climat., Amer. Meteor. Soc., Seattle, WN, 11-15 January.