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FIELD ANALYSIS AND VERIFICATION OF THE YANKEE TOTAL PRECIPITATION SENSOR (TPS-3100)

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Abstract-

The TPS-3100 instrumentation strives to improve the accuracy of precipitation measurements under lighter precipitation and snowfall events when other instruments often under-report. The instrument was deployed at the Spruces Campground in Big Cottonwood Canyon, a canyon in the Wasatch Mountains east of the city of Salt Lake City, UT, to mixed results. Although correlation existed between the Gauge and the TPS-3100 for storm events, the hotplate reported far too many precipitation events on clear air days and over reported storm totals. This highlights an apparent weakness with the TPS-3100 sensors, making them impractical for some applications in mountainous terrain as presently configured.

Background-

Due to its socioeconomic implications, humanity has a fairly extensive history in measuring precipitation. The importance of accurate precipitation measurement becomes of even greater importance when the uncertain impact of a warmer planet is accounted for. Over the past century, changes in precipitation have been observed that have been too significant in magnitude to be accounted for by measurement biases alone (Diaz et al. 1989, Vinnikov et al. 1990). While the potential implication of these changes is currently far from certain, it creates a situation where monitoring precipitation accurately becomes critical to understanding what a warming planet may mean for future climatological trends.

With a wide range of potential instrumentation to choose from, the question then becomes which we should use to get the most accurate measurements. A historical survey of the

USSR's use of precipitation measurement (Groisman et al. 1991) dates the region's measurements back as far as 1830. Since the former USSR took up nearly one sixth of the Earth's landmass, precipitation totals varied greatly across the country, leading to a unique challenge for recording meteorological observations. Measurements were first recorded only in industrial cities through the Department of Mines before eventually growing to tens of thousands of sites by the 1980s. Due to the mid-latitude location allowing for both frozen and liquid precipitation, even the first instruments attempted to measure the liquid content of frozen precipitation.

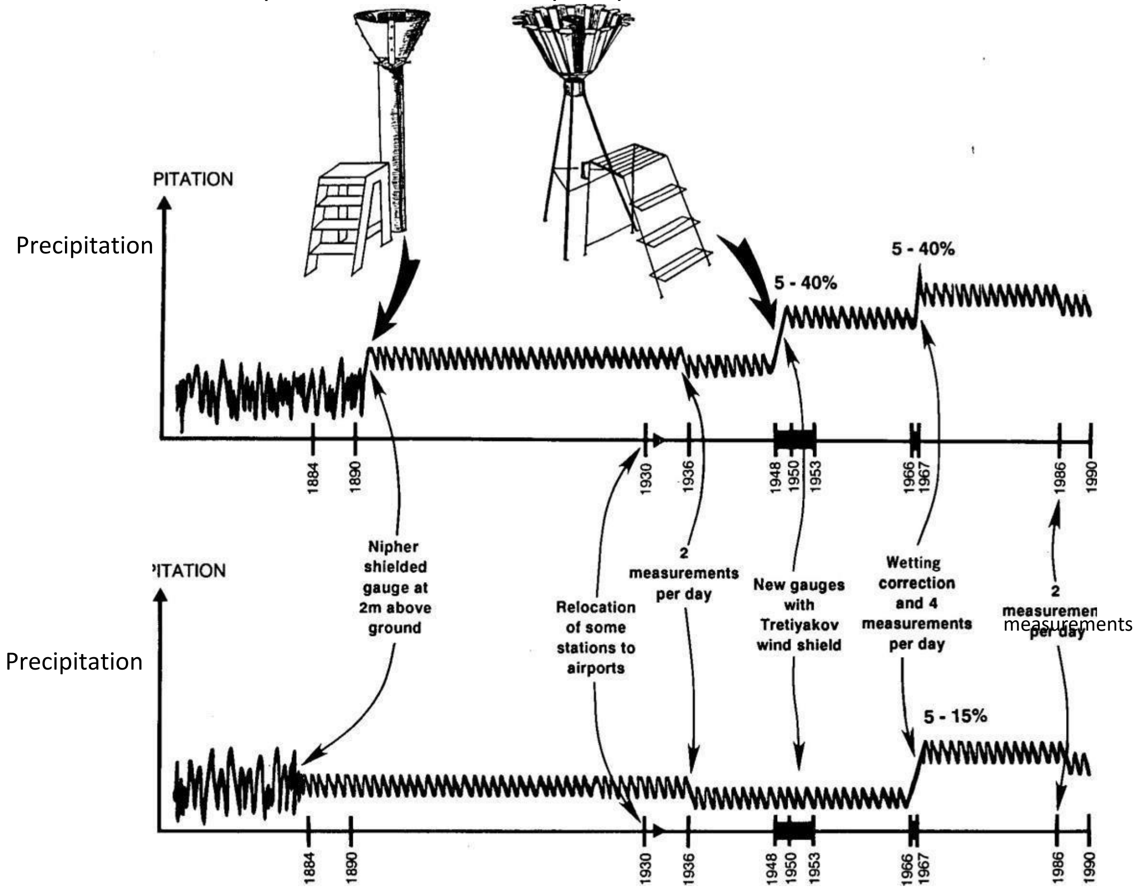

FIG. 1. An illustration depicting the systematic changes in the precipitation network over the USSR (Groisman et al. 1991)

As depicted in figure 1, several key advancements helped to improve the measurement at these stations. Among these were the installation of wind shields, site relocations, and the wetting correction. Still, despite these corrections and improvements, errors of up to 10% are still commonplace in observations.

In the United States, the primary form of precipitation measurement has been, and often continues to be, the tipping bucket instrument. The system works to collect precipitation (which it melts to a liquid equivalent if frozen) and then pours it out once it reaches a certain threshold. This instrument still has significant drawbacks, however. The tipping bucket system has been shown to suffer from significant errors on smaller time scales of less than 10-15 minutes (Habib et al. 2001). In addition, minimal precipitation amounts are neglected if they fail to reach the threshold required for measurement. Despite this, it has been asserted that these gauges can provide an accurate measurement if proper correction software is applied (Lanza & Stagi).

The TPS-3100 instrumentation attempts to improve on the deficiencies of the tipping bucket system. Through the use of two independently heated plates connected by a thermal tube, it is possible to obtain real-time precipitation measurements based on the energy required to maintain a constant plate temperature (Halet et al. 2003). The top plate is exposed to precipitation, while the bottom one is shielded by the top plate. Thus, during precipitation, it will take more energy to keep the warmer top plate at a constant temperature than the bottom plate (Rev 2012). This method of measurement will allow for more accurate precipitation measurement during both very light and very heavy precipitation events that other precipitation instruments often struggle with.

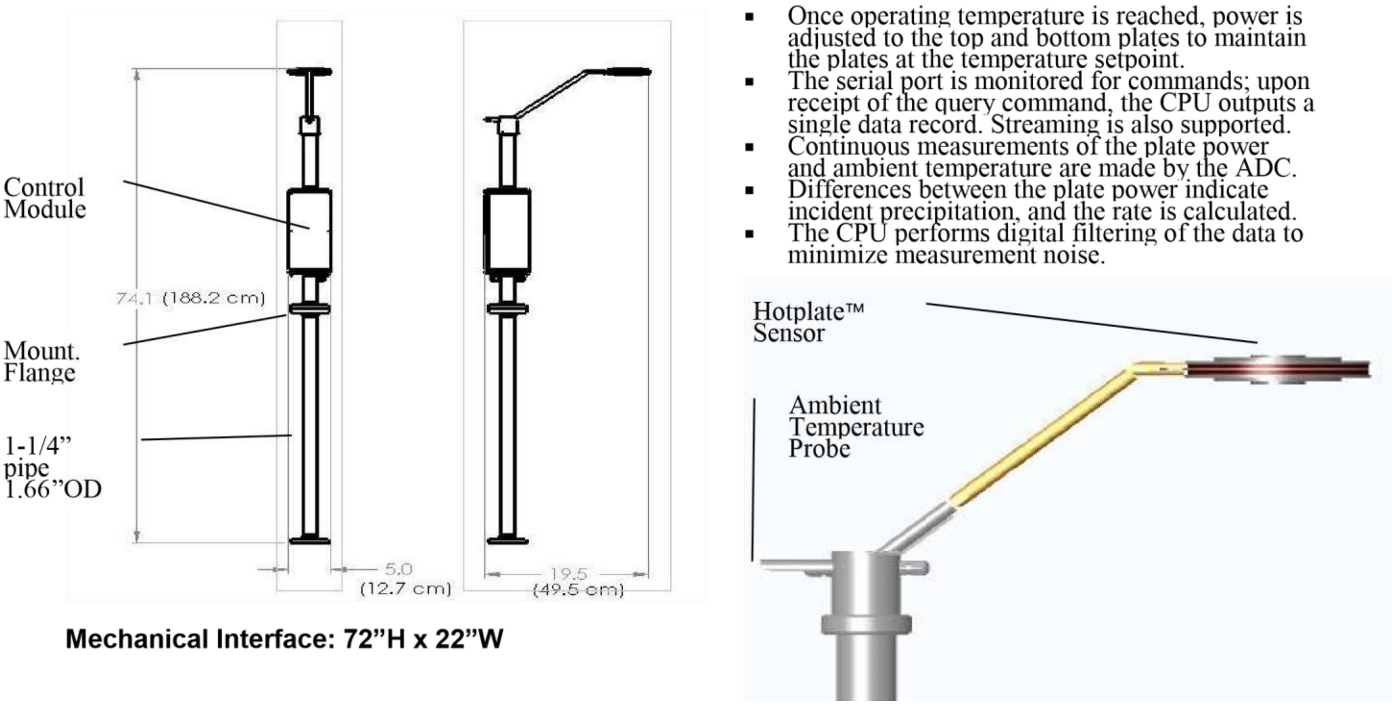

FIG. 2: Schematic of TPS-3100 and basic principles of device functionality (Yankee Environmental Systems, 2005)

Methods-

Before deploying the instrument, a great deal of consideration was put into the siting.

The TPS-3100 manuals instruct the user to use a flat, open space with a minimal amount of obstruction. Locating a position that matched these conditions within the state of Utah that also received consistent snowfall proved challenging. Ultimately, the Spruces location was chosen due to being a relatively level and open environment, as well as its accessibility and availability of comparable data nearby. The primary disadvantage of the site was a large quantity of pine trees surrounding it with the potential to capture falling precipitation before it hit the ground, or possibly shed snow on the sensor at times when precipitation wasn't falling.

FIG 3: Photo taken of Hotplate and surrounding site on day of deployment before any snow fell

In order to feasibly deploy the instrumentation, it was necessary to record the data via a pre-developed program. This was done by configuring the hotplate instrumentation to output data to a Campbell Scientific CR1000 data logger, which allowed for data collection without a direct connection to a computer. A program was written, entitled "Hotpants," which had the hotplate automatically communicate all applicable station information (temperature, precipitation total, etc.) via the onboard serial port every minute. A wireless communicator then sent this information to Mesowest, giving us a medium through which to view the data.

Liquid Precipitation Equivalent (LPE) was measured as a daily total recorded by the sensor, with the total resetting at local midnight. Thus, an ongoing daily total was available at 2359 MST that was used for our comparison. The hotplate was deployed on November 5, 2016, and recorded information until it began to cease communications with Mesowest on January 13, 2017. Once communications ceased, the station was taken down about two weeks later due to an inability to resolve the communication issue. All relevant data was downloaded from the Mesowest archive for the period of time we had available and compared against the data from the Utah Department of Transportation's sensor nearby. Additionally, a manual observation was done for a 48-hour interval from January 11-13 for an incoming storm. The LPE for the event was obtained by setting out a snowboard to use as a base for the measurement and taking a core of the freshly fallen snow via a coring tube. This manual observation was then compared to both the hotplate and the gauge.

Results-

Due to the inactivity of the station beyond mid-January, the results provided by the station were somewhat limited. However, when the Hotplate was compared to the other indicators available, some troubling results were discovered. During a snowfall event occurring from January 11-13, the Hotplate was directly compared to a manual observation taken in the vicinity (within 10 meters) of the instrument. When the core was taken and melted down, approximately 11.9 mm of LPE were recorded. Meanwhile, the Hotplate recorded 39.9 mm, which was an over report of approximately 28 mm for the time period. With manual observations generally being regarded as the most accurate method for evaluating the precipitation output of a storm, the instrument's major overestimate of LPE was concerning.

Given the close proximity of the station to UDOT's gauge, the best evaluation of the instrument's performance may be to compare the LPE measured by the two stations over the time period it was deployed. Figure 4 shows a direct comparison of the outputs of the hotplate versus the gauge, which indicated that on days both the gauge and the hotplate recorded precipitation, the readings were relatively close aside from a few outliers. However, the figure also highlights the primary concern of the hotplate's output. After being deployed for a period of approximately two weeks, the TPS-3100 began to record false precipitation events in which the sensor recorded periodic increments of precipitation on clear air days.

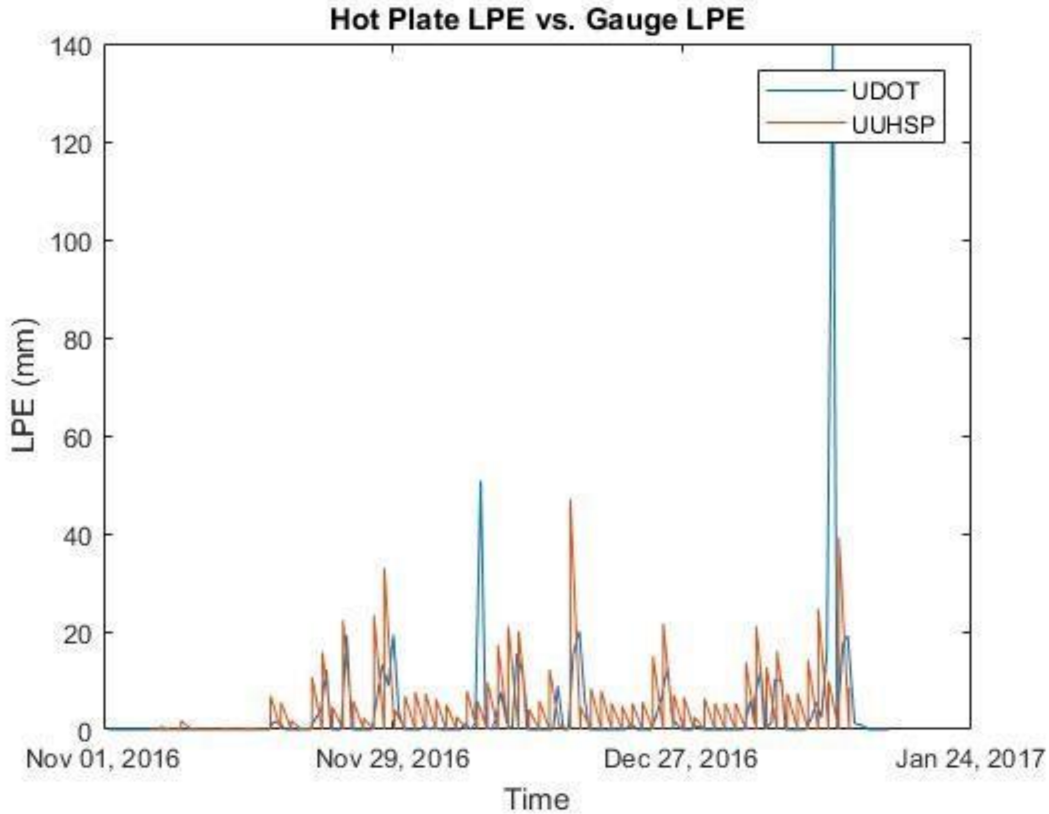

FIG 4: LPE output (mm) of the gauge and hotplate during time hotplate communications were active

These readings were sporadic at first before increasing in frequency until they began to occur daily. In addition, once these false readings began to occur, the hotplate began to over report LPE on days that precipitation DID occur. This bias toward over reporting can be seen in figure 5, which shows the correlation of precipitation outputs from the hotplate and the gauge relative to a 1:1 line. This analysis omits days where the instruments recorded no precipitation, as well as significant outliers (days with a LPE exceeding 60 mm). The data is strongly skewed to the left, indicating an over reporting bias by the hot plate sensor.

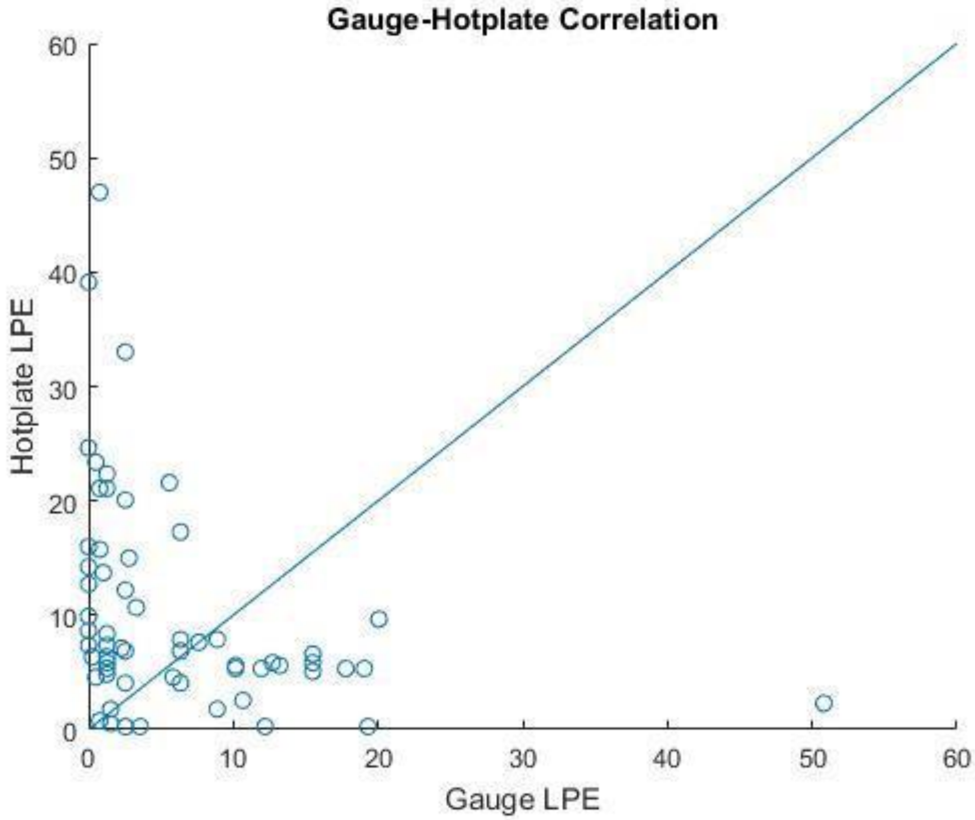

FIG 5: Hotplate and Gauge LPE correlation relative to a 1:1 line

Analysis-

The TPS-3100 advertises itself as being able to more accurately measure small amounts of precipitation than a typical precipitation gauge, but the results of this study seem to show that the greater sensitivity of the instrument has its flaws. Perhaps the over reporting of the sensor can be attributed to (at least in part) the location in which it was deployed. Yankee Environmental Systems states in their manual that the siting should be an “open flat field.” (Rev, 2012). However, the feasibility of deploying the instrument in an idealized environment such as this is difficult, especially in a complex environment like Utah. While the site loosely met these criteria, the close proximity of dense pine trees, as well as the enclosed environment of the canyon were certainly factors that could’ve caused the instrument to malfunction.

Another challenge presented by deploying the TPS-3100 in this environment was its inability to remain online throughout the entire intended study period. When deployed in

November, the initial goal had been to monitor the station through the entire winter season (i.e. through at least early March). With the station unable to continue reporting normally throughout the intended time period, its reliability in a mountainous region can be questioned. It remains unknown exactly what caused the station to go offline, though several possibilities exist, including a malfunction of the instrument, and a malfunction of the communicator reporting the data to the Mesowest system.

Ultimately, the results of this study point toward several significant concerns with deploying the TPS-3100 for accurate LPE measurements in a mountainous environment. Until these difficulties are resolved by the manufacturer, gauge measurements and manual observations serve as more reliable reporting methods.

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