6.3 SUNSHINE SENSOR TESTING FOR ASOS PRODUCT IMPROVEMENT

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1. INTRODUCTION

The National Weather Service (NWS) Automated Surface Observing System (ASOS) Product Improvement (PI) staff began evaluating candidate sunshine sensors in 1992. Several types of sensors were tested at the Sterling, Virginia test facility. Tested sensors included the Foster-Foskett sunshine switch, which is the current NWS operational instrument for measuring sunshine duration. Only one sensor, the EKO MS-091, performed within the ASOS requirements for sunshine duration when compared to the Eppley Normal Incidence Pyrheliometer (NIP).

EKO Instruments Trading Co., LTD was awarded a contract by the NWS in 1995 for a quantity of MS-091 analog sunshine sensors. These sensors were tested at four climatologically diverse field sites in the United States against the Eppley NIP between March, 1996 and March, 1998. Results of the test showed the EKO/Eppley comparisons were within the ASOS requirements for sunshine duration (Raytheon ITSS, 1998).

Additionally, eight NWS field sites equipped with the Foster-Foskett volunteered for a one-year EKO demonstration test between March, 1997 and August, 1998. EKO analog sensors were deployed at the eight sites collocated to the existing Foster-Fosketts. Results of the demonstration test provided the NWS with positive and favorable responses from the field sites. The EKO sensors performed well with minimal maintenance problems.

Subsequent to the EKO MS-091 sensor tests, a solicitation was issued and a development contract awarded to EKO in August, 1998 for a small quantity of MS-092 digital sensors. Initial test results obtained in 1999 at the Sterling, VA test facility revealed several issues related to self-tests, diagnostics, and sensor calibration which required changes before proceeding with further tests. The units were modified by the vendor and returned to Sterling, VA in mid 2000 for a re-test.

This paper presents the data analysis and results of the EKO MS-092 digital sensor re-test performed from October, 2000 to July, 2001 at the Sterling, VA test facility and discusses a proposed reporting algorithm.

2. TEST APPROACH

Currently, sunshine duration measurements in the United States are reported from ~100 NWS surface weather observing stations using the Foster-Foskett sunshine switch (A-081). Testing by Hughes STX has shown that the potentiometer in the Foster-Foskett requires frequent adjustment to maintain a consistent voltage threshold for sunshine (Hughes STX, 1996). Therefore, the sensor was found to be impractical for use in an automated system.

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2.1 *EKO Sunshine Sensor*

The EKO MS-092 digital sunshine sensor (Figure 1) consists of a special reflective mirror rotating within a glass tube, with a pyroelectric sensor mounted at the end of the glass tube. The pyroelectric transducer outputs an electric signal proportional to the direct solar radiation intensity. The latitude is set with the latitude scale plate to match that of the measuring site. A solar noon alignment is required during initial setup using the S-N indicator and line marker on the instrument. The sensor's reflective mirror is driven by a stepper motor so that it rotates once every 30 seconds. The MS-092 sensor incorporates digital electronics for self tests, diagnostics, and RS-232 communications.

The EKO heater functions at temperatures lower than about -20EC to prevent excessive chilling of the pyroelectric transducer. No heaters were tested due to the lack of cold weather. The blower is mounted below the glass tube and operated continuously to prevent dew or frost from accumulating on the glass.

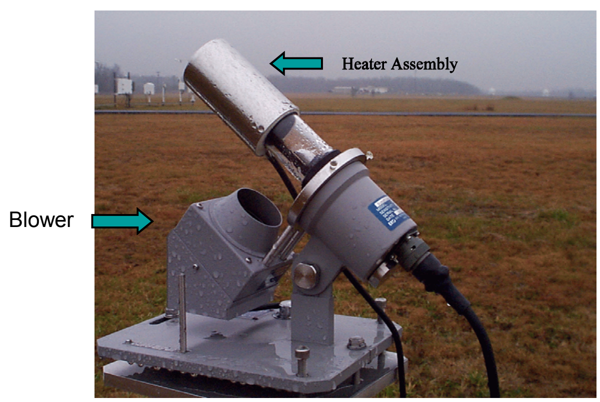

Figure 1 EKO MS-092 with Heater

The EKO MS-091 analog sensor is similar to the digital version; it does not incorporate digital electronics.

2.2 *Eppley Normal Incidence Pyrheliometer*

The reference sensor for this test was the Eppley NIP, which is part of the Integrated Surface Irradiance Study (ISIS) test with the cooperation of Dr. Detlef R. Matt, NOAA/ERL/ARL, Oak Ridge, TN.

The Eppley NIP incorporates a wire-wound thermopile at the base of a tube, the aperture of which represents a ratio of 1 to 10 of its length, subtending an angle of 5.7 degrees. The pyrheliometer is mounted on a gear drive model, two axis positioner, SCI-TEC solar tracker (Figure 2) which provides continuous readings of direct incoming solar radiation. One-second readings from the Eppley NIP are averaged to provide a one-minute solar flux value. Calibrations of the Eppley NIP are traceable to the National Standard Radiometer.

Figure 2 Eppley NIP on solar tracker

2.3 *Meteorological Performance Criteria*

Revised meteorological performance requirements for sunshine sensors were issued in April, 1998 by the NWS in specification no. NWS-A085-SP1000 and are as follows:

1) The daily total minutes of sunshine derived from the sunshine sensor shall be within ±10% of the daily total minutes of sunshine derived from an Eppley NIP when compared over a 30-day interval.

2) The cumulative direct solar radiation reported by the sunshine sensor shall be within ±10% of the cumulative value as measured by the Eppley NIP over a 30-day interval.

3) During cloud-free periods, the hourly average solar radiation value derived from the sunshine sensor shall be within ±10% of the hourly average solar radiation derived from the Eppley NIP.

The output from the sunshine sensors were used to derive daily minutes of sunshine, where a minute of sunshine was defined as any minute with direct solar radiation \$120 watts/meter² (W/m²) in accordance with the WMO recommendation for a sunshine threshold.

2.4 *Data Collection*

Each minute, the larger of the two output values from the EKO digital test sensors and EKO analog comparison sensor (#15), were saved in a Personal Computer Data Acquisition System (DAS). Daily EKO sensor files were copied to a Zip disk. The Eppley NIP one-minute data and the maximum one-minute data from the second EKO analog comparison sensor (#3), were stored in the ISIS data logger. These data files were downloaded via telephone modem.

2.5 *Data Analysis*

Four EKO MS-092 digital sunshine sensors at a time were deployed for 60-day intervals at the test facility in Sterling, VA, between 20 October, 2000, and 29 July, 2001. The data obtained from nine digital test sensors were compared to the output from a collocated Eppley NIP. Additional comparisons were made to the output of two analog EKO MS-091 sensors deployed in the same test bed to determine any differences between them and the digital MS-092 sensors.

Routine maintenance of the Eppley NIP was performed. It was cleared of all snow/ice, frost, dew, or dust deposits on an as-needed basis. The EKO sensors were visually inspected, but only cleaned at approximately 90-day intervals in accordance with ASOS maintenance guidelines.

The Eppley NIP data were used to determine the level of compliance of the units under test to the ASOS performance requirements. Data from the Sterling, VA test bed were analyzed in three sections: Sunshine Duration, Cumulative Direct Solar Radiation (irradiance), and Hourly Average Solar Radiation during cloud-free periods. The following metrics were calculated and multiplied by 100 to obtain percentages:

1) Sunshine Duration (% Difference)

$$\frac{\text{EKO Sunshine Minutes } \& \text{ Eppley Sunshine Minutes}}{\text{Total Eppley Sunshine Minutes}}$$

2) Cumulative Direct Solar Radiation (% Difference, % within Requirement)

$$\frac{\text{Total EKO Irradiance } \& \text{ Total Eppley Irradiance}}{\text{Total Eppley Irradiance}}$$

$$\frac{\text{Number 30\&day Periods EKO within Requirements}}{\text{Total 30\&day Periods}}$$

3) Hourly Average Solar Radiation (% within Requirements, Average % Difference)

$$\frac{\text{Number of Hours EKO within Requirements}}{\text{Total Hours}}$$

$$\frac{\text{Sum of Hourly Differences}}{\text{Total Hours}}$$

The DAS was programmed to generate error files if any sensor under test reported a malfunction or missed a data poll. Daily files were scanned for any additional anomalous data produced by the units under test.

3. RESULTS

The Eppley NIP reports a one-minute average solar flux value, while the EKO sensors report a one-minute maximum. This difference in reporting methods produced larger variances when solar flux amounts were reduced due to persistent cloud cover and when values increased or decreased rapidly. Reported EKO maximum values were mainly higher than the averaged Eppley NIP reports under the following conditions:

1) mostly cloudy sky conditions when the sun was frequently hidden or partially hidden by cloud cover
2) during periods immediately after a clear sunrise and prior to a clear sunset
The response time of the EKO mirror activated sensors was apparently faster than that of the Eppley NIP.

3.1 *Sunshine Duration*

All of the EKO sensors were within the ASOS requirements for sunshine duration. When compared to the Eppley NIP, the percent difference of the test sensors ranged from +2% to +8% for minutes of sunshine.

3.2 *Cumulative Direct Solar Radiation*

Three of the nine digital EKO sensors (#5, #9 & #13) did not meet the requirements for cumulative direct solar radiation over 30-day intervals in comparison to the reference. The three sensors were >10% higher than the reference during each 30-day test period.

Additionally, test sensor #14 was 10% to 12% higher than the reference during one 14-day period. Overall, the sensor was within the requirements 76.7% of the time over its 120-day test. Mostly cloudy conditions during the 14-day period caused reduced totals of solar irradiances as measured by the Eppley NIP. Apparently, the reduced totals contributed to the failure of sensor #14 in meeting the requirements 100% of the time.

Reduced totals of solar radiation in this same period also apparently affected the accuracy of the two analog comparison sensors. Neither of the two analog sensors met the ±10% requirement at times during the same 14-day period.

Table 1 Comparison of Total Direct Solar Radiation

EKO Sensors	% Difference from Eppley	% 30-day Periods within Requirements
EKO 3A	+7.35	94.2
EKO 15A	+6.50	97.5
EKO 5D	+29.11	0
EKO 7D	+5.55	100
EKO 8D	+4.13	100
EKO 9D	+12.63	0
EKO 10D	+5.60	100
EKO 11D	+5.44	100
EKO 12D	+8.75	100
EKO 13D	+14.27	0
EKO 14D	+7.55	76.7

Table 1 lists the overall percentage differences of the EKO sensors from the reference for the cumulative direct solar radiation comparisons. The two sensors listed first are the analog comparison sensors followed by the digital units under test.

3.3 *Hourly Average Solar Radiation*

During cloud-free sunny periods, the hourly solar flux values from the EKO sensors and the reference sensor were averaged and compared. Test sensors #5, #9 and #13 failed to meet the requirement for average solar radiation during cloud-free periods (±10%, 100% of the time). These three sensors also failed to meet the cumulative direct solar radiation test metric.

Table 2 Comparison of Hourly Average Solar Radiation

EKO Sensors	% of Hours within Specification	Average Hourly % Difference
EKO 3A	93.0	+4.4
EKO 15A	94.7	+0.4
EKO 5D	0	+21.1
EKO 7D	100	+0.9
EKO 8D	100	-2.2
EKO 9D	93.7	+5.8
EKO 10D	100	+0.8
EKO 11D	100	+1.4
EKO 12D	100	+3.0
EKO 13D	83.1	+8.0
EKO 14D	100	+1.2

In Table 2, the percentage of hourly average solar flux comparisons during cloud-free periods which were within the ±10% requirement are summarized. The analog comparison sensors were within the ±10% requirement 93% and 94.7% of the time. The variance was seen primarily during periods just after sunrise and just before sunset, when the analog sensors reported significantly higher solar flux values than the Eppley NIP.

Digital sensor #5 reported significantly higher solar flux values throughout both periods it was under test.

The third column lists the average differences between the the EKO sensors and the reference for the hourly comparisons calculated over the four test periods.

3.4 *Engineering Issues*

During the initial MS-092 tests at Sterling in late 1999, several of the test units reported low level flux values at night. These values ranged from 1 to <5 W/m². The lowest reported flux value from the digital sensors was reset by the vendor at 5 W/m². The output from three sensors under test (#5, #8 & #14) reported intermittent low level flux values at night that ranged from 5 to 8 W/m².

Anomalous data, erroneously reported as “pass”, were reported after power interruptions. All of the digital sensors reported false sunshine at night on two occasions following power interruptions. The sensor’s output was checked and found to contain reported flux values to over 2000 W/m², with some marked as “pass”. The issues related to low-level night time flux values and erroneous data flagged as “pass” have not been corrected.

Other issues, which included faulty sensor diagnostics and self-tests, did not occur in the re-test.

4. CONCLUSIONS

All nine EKO MS-092 digital sensors and all analog sensors tested fully met the ASOS requirements for sunshine duration.

Five of the nine digital sensors under test fully met the ASOS requirements for cumulative direct solar radiation.

Six of the nine digital sensors under test fully met the ASOS requirements for hourly average solar flux during cloud-free periods.

The calibrations of three units (#5, #9 & #13) need to be verified and the quality control for calibrations needs to be improved.

Six digital sensors under test did not report solar flux values at night. Low level solar flux values were recorded at night from the remaining three units under test. This anomaly needs to be addressed.

Finally, the EKO MS-092 sensor electronics supplied for this re-test produced anomalous data following power interruptions on two occasions. It was concluded that more development work is required to correct issues related to the electronic interface units.

5. PROPOSED REPORTING ALGORITHM

The climatological record of sunshine duration includes a variable amount of minutes of sunshine added by human observers. Observers have historically added minutes of sunshine at clear sunrises and sunsets to account for obstructions such as hills or buildings blocking the sensor from receiving direct sunlight. The amount of time required for the sensor to respond to sunlight was also accounted for by adding minutes of sunshine to the observed total. These historical observing procedures present a challenge for those trying to automate observations with an eye toward preserving a degree of climatological continuity for sunshine duration.

A study was conducted by Hughes STX for the ASOS PI staff in 1997 to determine the standard solar elevation angle at which the EKO sensor exceeds the WMO recommended threshold of 120 W/m². The results of the study concluded that under clear atmospheric conditions, the solar elevation angle when the EKO exceeded 120 W/m² would be near 0E. Therefore, if the sensor is sited with an unobstructed view of the 0E horizon, a reporting algorithm would accurately calculate the total minutes of sunshine and percent of possible.

Since maximum possible daily sunshine tables exist on the ASOS site normals page for each site, a reporting algorithm can calculate the percent of possible sunshine at each site. However, not many sites have a clear unobstructed view of the natural horizon. ASOS requirements for a sunshine duration sensor state the sensor must report from 0 to 100% of possible for those days that are totally cloudy or totally clear. Even a relatively small obstruction would always prevent the sensor from reporting 100% of possible. Therefore, an obstruction algorithm is needed. Data collected from the one-year EKO field demonstration test in 1998 were used by Raytheon ITSS to develop an obstruction algorithm for possible use in automated systems.

The EKO demonstration site at the WFO in Corpus Christi, TX (CRP), provided a clear view of sunrise, but sunset was blocked by an obstruction. This blockage provided an opportunity to develop an obstruction algorithm. The NWS SUN.EXE program provides the sun’s location each minute at any known location using the latitude and longitude of the site.

The program operating on the DAS at the field demonstration sites computed a running percentage of sunshine duration during the previous 60 minutes. The percentage value observed over the 60-minute period adjacent to the obstruction was applied to the period of blockage by extrapolation. The extrapolated number of minutes of sunshine were then added to the daily total to compute the percent observed for the day.

The corrected monthly totals for minutes of sunshine calculated from the EKO sensor with the extrapolated amounts added, were within 1% of the official total of minutes of sunshine reported by CRP. At the one site with obstructions which affected both sunrise and sunset and were greater than 10E in elevation (Binghamton, NY), there was less accuracy (-4.5%) in the proposed extrapolation method.

Some obstructions will likely be encountered where sun sensors are deployed. Therefore, a Program Design Language (PDL) obstruction algorithm has been developed and can be implemented at observing sites.

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