Responsivity of an Eppley NIP as a Function of Time and Temperature

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Abstract:

Introduction:

The best way to obtain accurate direct normal beam data is to measure the insolation with an Absolute Cavity Radiometer (ACR). The absolute accuracy of an ACR is on the order of 0.5% and field ACRs with windows may have a slightly larger uncertainty. Because of care and expense of using an ACR, a first class Normal Incident Pyrheliometer (NIP) is often the instrument of choice. The absolute accuracy of these instruments is on the order of 2-3%. These instruments claim to have a temperature stability of about 0.5% and there responsivity changes little from year to year. It is difficult to measure the NIP's temperature dependence in the field and to determine the rate of change of its responsivity over time because of the 2-3% uncertainty in calibrating the NIP. This study presents a detailed study of one Eppley NIP calibrated frequently against an ACR over a 5 year period and demonstrates of the stability of the responsivity and temperature dependence of the instrument over the period.

The limited accuracy of the calibrations and the uncertainty about the stability of the instrument response over time leads to practical problems when measuring solar radiation. When NIPs are calibration against Absolute Cavity Radiometers (ACR), should the resulting calibration factor[1] be used each time the NIP is calibrated or should the calibration factor be changed only after a trend is determined? If the NIPs are very stable (responsivity changes by 0.1% or less per year) then the calibration factor used for the instrument should be changed only when a trend is found. In a network, should NIPs be rotated and brought in for calibration every year? If NIPs are very stable, it is better to leave the NIPs at the site and perform site calibrations to ensure the are no sudden changes in calibration. Changing the NIPs out by rotation would add scatter to the relative uncertainty of the data. Even if the NIP is sent to a lab for calibration then, for the least relative uncertainty in the data, the NIP should then be replaced at the same site after the calibration is completed. If the response of the instrument changes by about 1% per year, then it is probably more practical to rotate the instruments and keep the calibration information up to date.

Knowledge of the rate of change of the responsivity of the instrument also influences the evaluation and methods of rehabilitating data gathered from instruments that were not routinely calibrated.

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[1] The responsivity of an instrument is 1 divided by the calibration factor.

This article is organized as follows. First, the calibrations of the instrument are described along with the uncertainties in the measurements. Next the method used to extract the information is illustrated and finally the results and conclusion of the study are presented.

Calibrations of the NIP

The National Renewable Energy Laboratory (NREL) maintains a calibration facility at its Solar Radiation Research Laboratory (SRRL) in Golden, Colorado. This facility uses an Eppley HF Absolute Cavity Radiometer (ACR) that is periodically compared to the World Radiometric Reference. The SRRL facility often calibrates between 10 and 40 pyrheliometer and pyranometers at a time. The ACR is used to calibrate the pyrheliometers and the ACR along with a disk shaded pyranometer are used to calibrate pyranometers. As reference instruments, Eppley NIP 17836E6 and Eppley PSP 25825F3 are calibrated along with other instruments brought to the site for calibration.

In this study, calibration data from 1992 through 1996 are examined for Eppley NIP 17836E6. While each calibration episode results in values with a 2-3% absolute uncertainty, it is hoped that by combining all the data over each year, that the change in the response of the NIP can be evaluated to a much higher degree of accuracy.

In addition to the measuring the response of instruments, the BORCAL calibration data set also includes a temperature measurement taken near the body of a pyranometer. While this is not as reliable as a sensor attached to the body of the NIP, it does give a temperature scale against which calibrations performed under different temperature conditions can be gauged. This temperature measurement will be used to evaluate the temperature response of the NIP.

A plot of a day's worth of calibration data is given in Fig. 1. Data points with responsivity greater than 8.55 μV/m^2 and less the 8.35 μV/m^2 were eliminated from the data set. These limits were set to eliminate the occasional data point that enters the data set when optimum conditions are not met. (Examples of situations that would result in erroneous data points are measurements taken during partially cloudy periods, during recalibration of the ACR, or when there was dirt on the NIP window.) The eliminated data points are away from the body of the data.

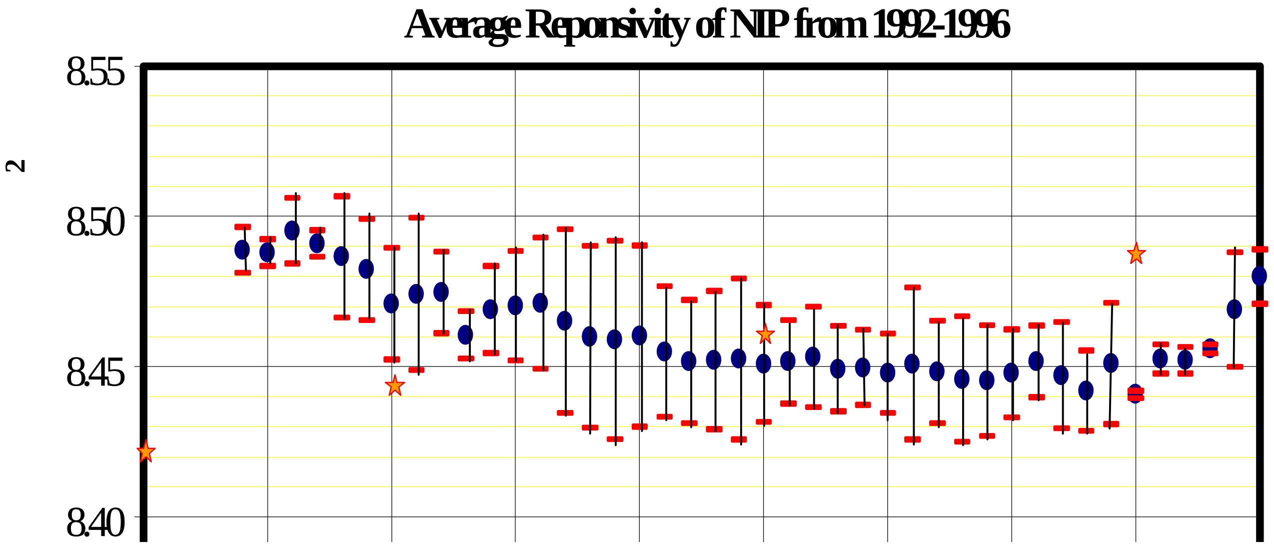

Fig. 1: Typical calibration data. Note the decrease in responsivity from morning values.

Two features typical of many daily sessions show up in Fig. 1. Often the first hour or two of data has responsivities that are higher than those taken during the rest of the day. The reason for this is unclear. Possible sources of error are listed in Table 1. Arrows in Fig. 1 point to the center of "peaks" in the responsivity. These peaks are often ½ hour to 1 hour wide and 0.05– 0.07 µV/m^2 in height. Again, the cause of these excursions in responsivity is unknown.

Table 1. Error Sources when Calibrating Pyrheliometers

Tracking errors: due to misalignment of the optical axis and diopter pointing mechanism on producing the pyrheliometers and misalignment of the pyrheliometer with respect to the sun, due to tracker performance (gear backlash, torsion effect, unbalanced loads)
Field of view: the NIPs have 5.7° field of view and they are usually calibrated using absolute cavity radiometers that have 5° field of view.
Temperature response: change of responsivity with the change of ambient temperature
Linearity: change of responsivity with the irradiance level
Turbidity: affects the geometrical and spectral distribution of the circumsolar radiation which, in combination with the spectral response and field of view, generates an error in irradiance measurement
Thermal electromotive forces: emf is produced due to thermal effects on signal connectors
Time constant: due to deference between the time constants of absolute cavity radiometer and pyrheliometer
Spectral response: due to different spectral response of the black detectors used in the pyrheliometers with respect to the cavity absorber in absolute cavity radiometers. Also pyrheliometers have windows on front of the detectors but absolute cavity radiometers are open cavities
Thermal gradients: due to incident irradiance and environmental conditions
Data acquisition system: due to the specifications of the data acquisition, it includes accuracy of measuring the output signal from the pyrheliometers and stability of the system until it is calibrated.

The uncertainty in the reference radiation as measured by the ACR is 0.46%. The sources of uncertainty are the measurement of the irradiance by the ACR and the accuracy of the data acquisition system. (See Table 2)

Table 2. Uncertainty in the Reference Irradiance

Source of Uncertainty	Uncertainty
Cavity Radiometer with respect to SI units	±0.41%
Data Acquisition	±0.2%
Total Uncertainty $u_{95} = \sqrt{U_{cav}^{2} + U_{daq}^{2}}$	±0.46%

Combining Calibrations

Since pyrheliometers are known to vary with temperature on the order of 0.5%, all the calibration data from a given year was combined to check if there was a consistent temperature dependence that could be extracted from the data. Figure 2 contains the data for 1994 for responsivity verses temperature. This figure represents approximate 20,000 data points taken over 30 clear days from April through September in 1994. Notice that the body of the data points lies well within the cutoff range of 8.35 to 8.55 outside the cutoff range of µV/m^2.

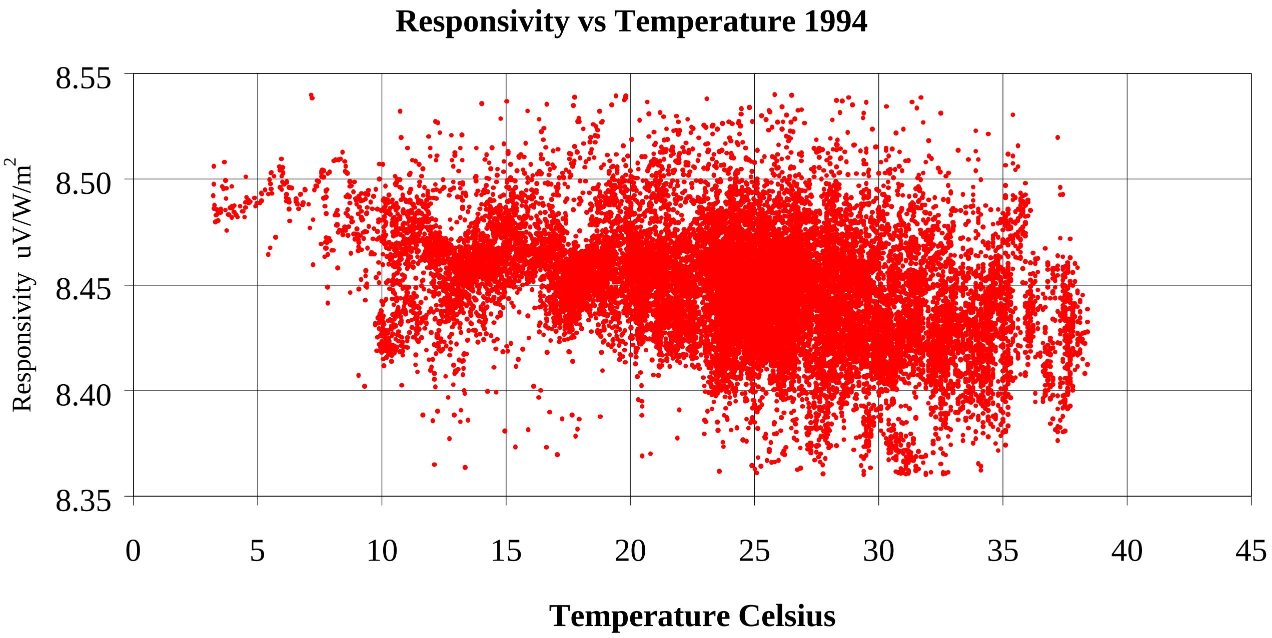

Fig. 2: Responsivity of NIP 17836E6 verses Temperature for all 1994 calibration data.

The responsivity in Fig. 2 appears to decrease with increased temperature. By evaluating the data in one degree temperature bins, the results do confirm that in 1994, there appears to be a decrease in responsivity as temperatures increase (See Fig. 3).

A limited amount of data is available at the extreme temperatures. For example below 8° C all data was measured on the morning of September 22, 1994. The first data taken during the day often have higher responsivities that data taken later in the day. This may be caused by the temperature dependence of the instruments or it may result from other causes. More data are

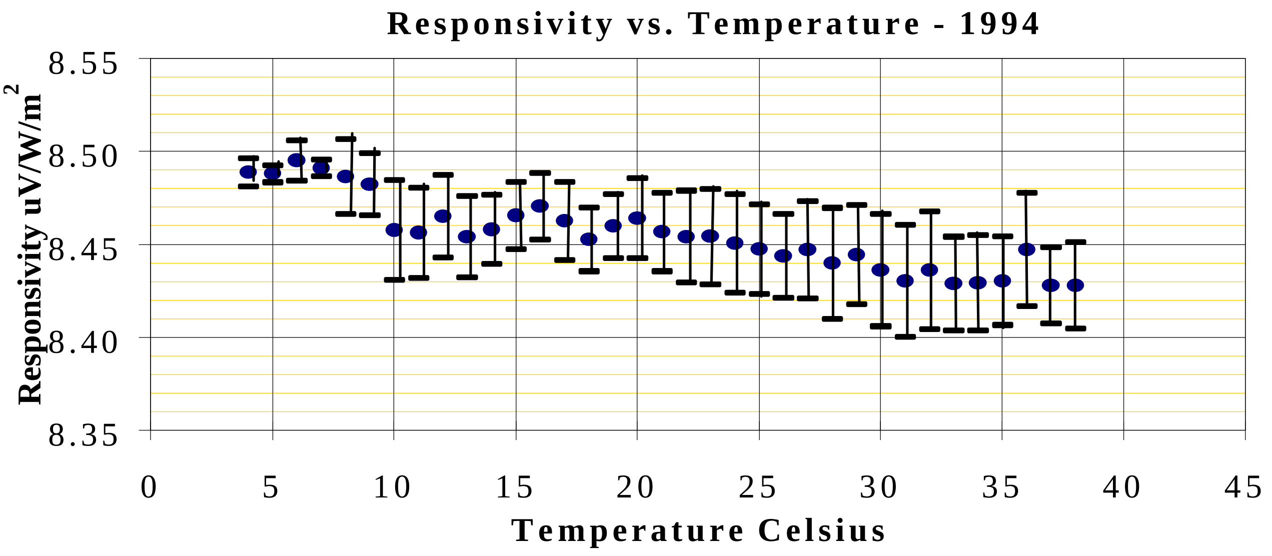

Fig. 3: Average responsivity verse temperature from1994 calibration data. The error bars represent 1 standard deviation. All values below 8° Celsius were measured on September 22.

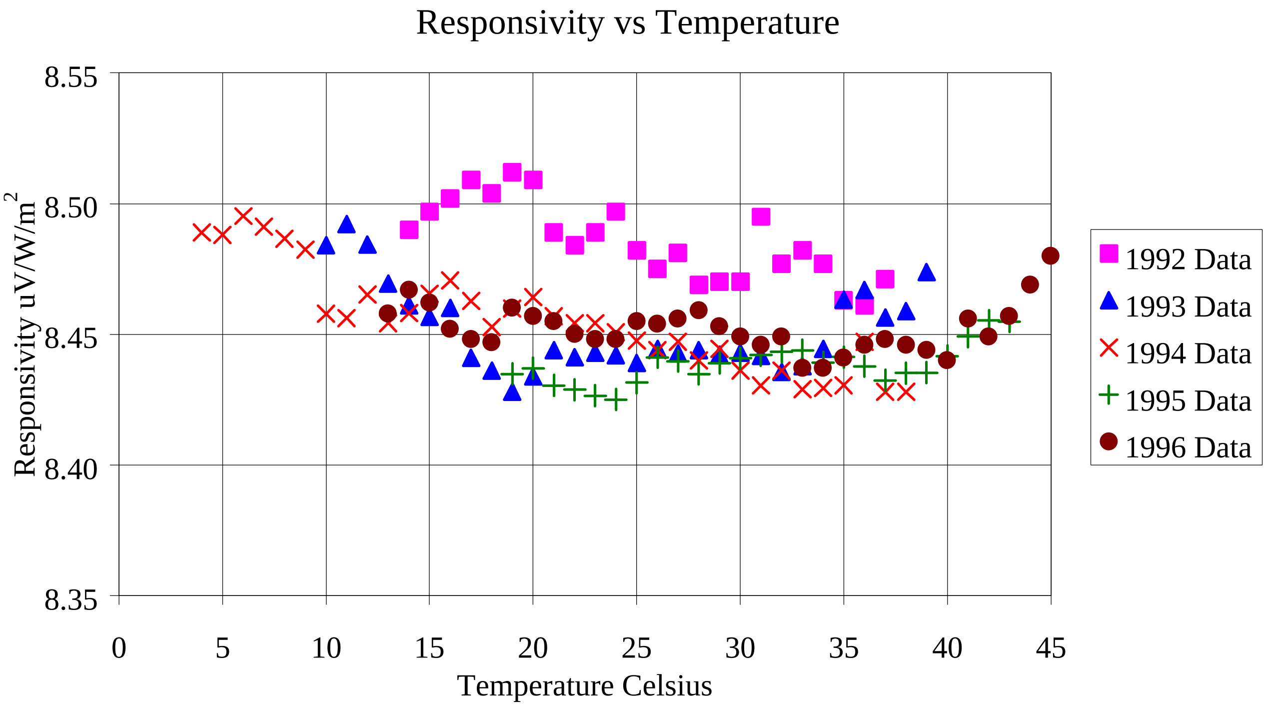

Fig. 4: Responsivity of Eppley NIP 17386E6 from 1992 through 1996 verses temperature. A systematic change with temperature is observed at about the same magnitude as the accuracy of the measurements. No trend is observed for a systematic decrease in responsivity.

need from measurements made during the temperature extremes to make a more firm statement about the nature of the temperature dependence of the NIPs.

Data in Fig. 4 shows the responsivity verses temperature for each year from 1992 through 1996. The responsivity of data from 1992 is higher than that found in later years. This difference is within the limits of accuracy of the measurements and demonstrates the limit of accuracy of the measurements. (Another possibility is that the atmospheric conditions such as turbidity may be different from the following years.)

The agreement of the data is really extremely close considering the uncertainty of the measurements are quoted at 2% or higher. This reason for the difference is two fold. First the measurements are shown as relative calibration numbers and not absolute calibration numbers. Second, the data have been plotted as a function of temperature and this accounts for the variance due to temperature.

One striking factor that does not appear in the data is a decrease in performance of the NIP over the five year period. From 1993 through 1996, no trend is observed and the data are consistent with no change in responsivity. If there was a systematic deterioration in the responsivity, it would have to be ~0.1% per year or less.

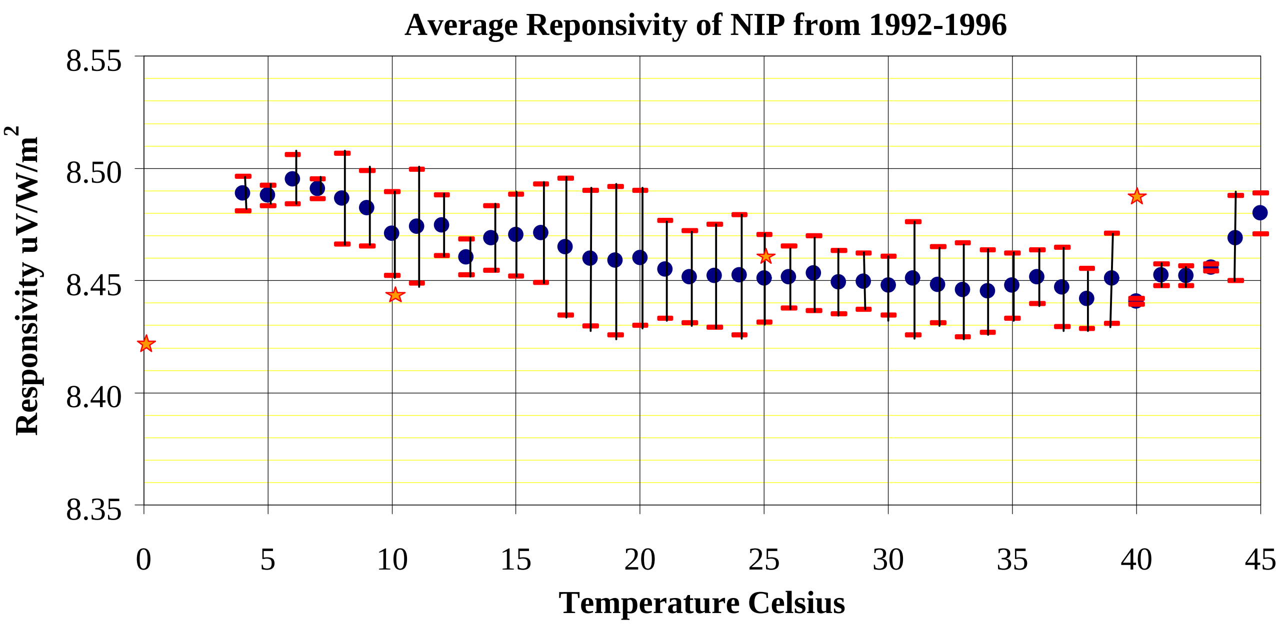

Fig. 5: Average responsivity of NIP 17836E6 verses temperature. Data from 1992-1996 combined. Each point is the average of 5 years of data and the error bars represent standard deviation. The stars are the relative temperature dependence of NIP 17836E6 reported by the Eppley laboratory in 1978.

A better look at the temperature response of the NIP can be obtained by combining all 5 years of data. The averaging is possible because there is a lack of observable deterioration of responsivity in the NIP. Fig. 5 contains the average responsivity of the NIP as a function of temperature.