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# AMBIENT TEMPERATURE EFFECTS ON BROADBAND UV-B MEASUREMENTS USING FLUORESCENT PHOSPHOR ($MgWO_4$)-BASED DETECTORS

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ABSTRACT

Results of field tests on a group of broadband UV-B Pyranometers are presented. A brief description of the instrument is given. The effects of ambient temperature on thermally unregulated fluorescent phosphor (Robertson type) meters are presented and compared with the performance of thermally stabilized instruments. Means for correcting data from thermally unregulated instruments, where the prevailing ambient temperatures are known, are outlined.

## I. INTRODUCTION

The measurement of solar radiation, in the UV region, at the surface of the Earth is a difficult task. Unlike the controlled environment of the laboratory, ambient conditions (temperature, cloud cover, air quality and even wind) can affect the accuracy and stability of the measurement. The measurement task is further complicated by the fact that the data needs of the UV research community are quite varied. Some researchers need to measure the solar spectrum with high spectral resolution. Others require the knowledge of the radiation in a narrow range of wavelengths. For some studies a wide geographical coverage is important while for others a single location is sufficient. No single instrument can meet the needs of all the researchers.

The development of the instrument described in this paper was prompted by the recognition of the need for a modest cost, broadband instrument which could be used in UV-B monitoring networks throughout the world. Primary instruments, such as reference spectroradiometers, are required to establish baseline data and serve as reference and calibration instruments for any network. However, the expense and complexity of these flagship instruments makes them impractical for use in networks where many instruments are used to cover a large geographical area. Much simpler, and less expensive, broadband UV instrumentation can be used to supplement the spectroradiometer measurements and extend the geographical range of UV monitoring. In addition, this type of instrument is particularly well suited for UV monitoring needs of developing countries with limited research budgets.

Broadband measurement of solar UV-B radiation with conventional optical detection schemes is difficult because the amount of energy present in the UV-B region of the solar spectrum is a small fraction of the total energy. In addition, most photodetectors have their peak spectral response in the visible, rather than in the UV portion of the spectrum. Since the 1930's, a number of techniques including chemical and radiometric, have been tried in an effort to measure solar UV-B irradiance. The current generation of broadband UV-B detectors is an extension of the work of Robertson (1972), who implemented the use of a UV-B sensitive fluorescent phosphor as the active element of his detector. Further refinements to the original Robertson meter were made by Berger (1976), hence some present day versions of this instrument are often referred to as Robertson-Berger meters, or simply R-B meters.

Building on the success of the original Robertson design, we sought to build an instrument which would meet the following basic criteria:

1) the instrument should employ up-to-date, high reliability components to assure maximum reliability in the field,

2) procedures for manufacturing and characterizing each instrument must be highly standardized and demonstrably reproducible,

3) errors due to thermal dependence of the output of the instrument must be eliminated,

4) procedures for establishing the cosine, spectral, absolute and thermal characteristics for the instrument must be standardized, NIST-traceable and transferable.

This paper describes the work done to eliminate the thermal dependence of the output signal (criterion 3). A paper with full description of the instrument and its calibration procedures has been submitted for publication in the Journal of Oceanic and Atmospheric Technology.

## 2. PRINCIPLE OF OPERATION

The operation of the instrument relies on a UV-B sensitive, fluorescing inorganic phosphor, magnesium tungstate ($MgWO_4$). This material, originally chosen by Robertson for his detector, absorbs incident UV-B light and re-emits it as visible (green) light. The re-emitted light can then be measured by a standard photodetector.

A schematic block diagram of the instrument is shown in Figure 1. Solar radiation, both direct and diffuse, passes through a UV-transmitting weather dome (Schott WG280 glass). The second element of the instrument is the pre-filter, a 1.6 mm thick UV-transmitting black glass (Schott UG11).

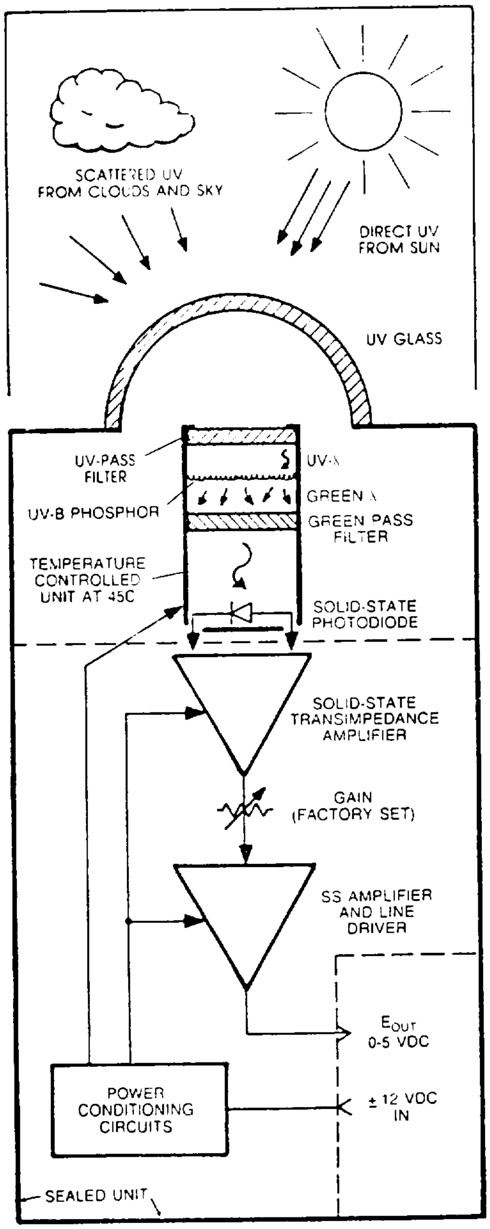


Figure 1. Schematic block diagram of the broadband UV-B detector.

This filter passes 80% of the incident UV-B light and absorbs all but a small fraction of the visible light. The only transmission band of the UG11 glass in the visible wavelengths is in the red region of the spectrum, around 750 nm, where it passes about 3%. A mixture of UV-B and red light, transmitted by the UG11, strikes the $MgWO_4$ phosphor. The red light is scattered, while the UV-B light is absorbed and re-emitted as visible (green) light. A 2.5 mm thick, green glass (Corning 4010) post-filter passes the fluorescent light from the phosphor, while absorbing the

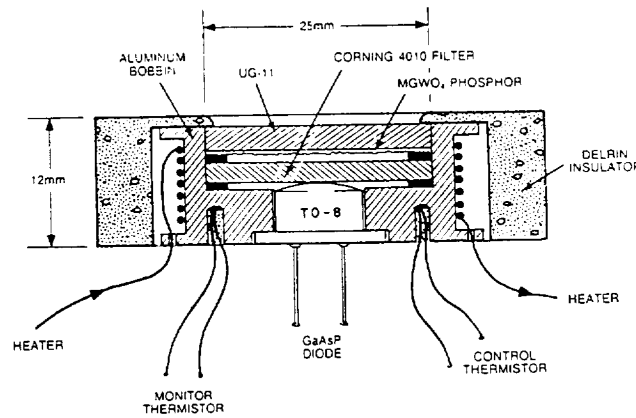


Figure 2. Cross section diagram of the detector sensor head.

remnants of the red light. The intensity of the fluorescent light is then measured by a Gallium Arsenide Phosphide (GaAsP) photodiode. This photodetector has its peak spectral response in the region of green light, dropping off rapidly at the longer wavelengths, thus further reducing the instrument's response to red light. A thermally stable transimpedance amplifier raises the output current level of the photodiode and drives a line amplifier to provide a low impedance 0-5 Volt DC output signal. Finally, since the performance of the critical components of the detection system, phosphor and photodiode, is temperature dependent, the instrument design incorporates a common, thermally controlled, holder for these elements.

A cross section of the instrument sensor head is shown in Figure 2. The upper ring is fabricated from Delrin to minimize thermal conduction to the body of the instrument. The UG11 pre-filter, with the phosphor layer deposited on its rear surface, the Corning 4010 post-filter and the GaAsP photodiode are mounted within an aluminum bobbin to ensure that these components remain at a common temperature. The bobbin is wrapped with a resistive foil heater, which is in good thermal contact with a control thermistor. An electronic circuit is used to thermally regulate the entire assembly, which is held at a constant temperature of +45 °C. This temperature is above the operating temperature of the instrument under normal field conditions. The control temperature can be made higher (lower) than +45 °C, if required for high (low) ambient temperature installations. A second thermistor allows the bobbin temperature to be monitored independently, if desired.

The amount of power required to maintain the bobbin assembly at +45 °C, with the ambient temperature of -40 °C, was measured to be approximately 5 W (0.4 A of current at 12 V). At a nominal ambient temperature of +20 °C, the required power is about 1.3 W. The thermal control circuit is designed to provide up to 0.5 A of current, from the 12 V supply, to the heater. The time required for the bobbin to reach the control temperature is less then 2 minutes, starting from a temperature of +20 °C, increasing to 12-15 minutes when the starting temperature is -40 °C. The warm up times become important in installations where power is limited and the instrument is operated on a cyclical basis.

The spectral response of the instrument is determined, on the short wavelength side, by the weather dome (WG280 glass) which absorbs light with wavelengths shorter than 280 nm. If it is required to measure the solar irradiance below 280 nm, a quartz dome can be substituted for the WG280 dome. On the long wavelength side, the spectral response of the instrument is determined by the excitation spectrum of the $MgWO_4$ phosphor.

## 3. THERMAL CHARACTERISTICS OF THE PHOSPHOR

The excitation and emission properties of the phosphor depend on its temperature and can introduce significant measurement errors if not accounted for or eliminated. Excitation of the phosphor occurs when one of the valence electrons in the $MgWO_4$ solid absorbs a UV photon and is promoted from the ground state to an excited state. The electron then undergoes interactions with the solid, losing some of its energy. Finally, the electron emits a lower energy (longer wavelength) photon, reflecting the fact that it lost energy to the solid, and returns back to the ground state.

The effects of increasing temperature on this process are two fold: 1) the effective ground state-excited state energy gap decreases in magnitude and 2) de-excitation modes, other than photon emission, become increasingly accessible to the excited electron. The result of the decreasing gap energy is to allow lower energy photons to excite the phosphor, thus shifting the excitation curve toward longer wavelengths. The effect of competing de-excitation modes is to decrease the probability of emission of the longer wavelength (visible) photon by the excited electron, thus lowering the phosphor efficiency as a converter of UV-B to green light.

The effect of temperature on the phosphor, and the instrument itself, can be seen from the information shown in Figure 3. Relative spectral response data for the instrument, measured at three different temperatures, are plotted with reference to the left hand axis. All data are normalized to the absolute spectral response at 0 °C and 292 nm. The simultaneous action of the two temperature effects is evident. As the temperature increases 1) the efficiency of the phosphor decreases and the peak of the relative spectral response curve decreases in amplitude and 2) lower wavelength photons can excite the phosphor and there is a slight, but significant, increase in spectral response for wavelengths longer than 305 nm.

The total effect on the instrument output, while in sunlight, can be arrived at by considering a typical solar spectrum in the UV region (30° zenith angle), plotted with reference to the right hand side axis in Figure 3. Since the solar UV spectral irradiance increases very rapidly with increasing wavelength, the effect of lower efficiency at the peak response (around 292-295 nm) is much smaller than the effect of the small increase in spectral response at wavelengths longer than 305 nm. The net effect, therefore, is to increase the instrument output as the temperature increases, when the instrument is illuminated by sunlight. The measured magnitude of this effect is +1.0%/°C. Note that if the instrument is illuminated by a Xe arc lamp, with a relatively uniform spectral output in the UV, phosphor efficiency effect dominates, and the measured instrument output changes by -0.5%/°C. Our measured values of the temperature coefficient are in good agreement with a previous measurement by Blumthaler and Ambach (1986).

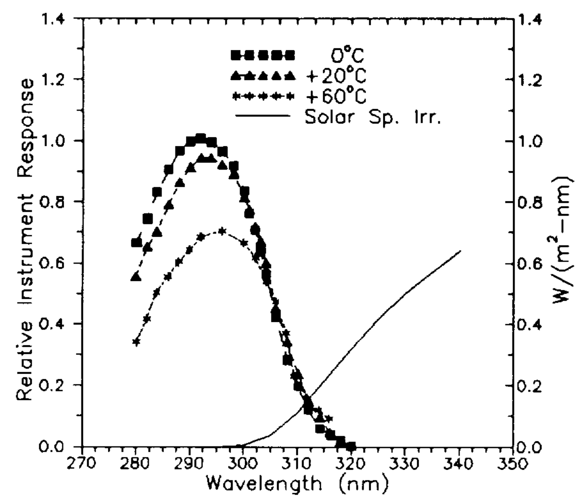


Figure 3. $MgWO_4$ phosphor relative spectral response; dashed curves are drawn to guide the eye. Solid line is a calculated solar irradiance spectrum.

The effect of phosphor temperature on instrument output is shown in Figure 4. The data were taken on 11/24/91 in western Massachusetts (42.5 °W, 72.5 °N) on a mostly clear day with ambient temperatures around +5 °C. The solid curve is the output of a unit with its bobbin thermally regulated at +45 °C. The dashed curve is the output of a test unit which starts the day with its thermal regulation turned off. As the expected, the thermally controlled unit records a higher output, although as the test unit warms up in the sunlight, the gap in output decreases slightly by 09:30. At 11:30 the test unit heater is turned on. Within minutes, the test unit bobbin reaches the control temperature and the two units track together for the remainder of the day.

## 4. INSTRUMENT PERFORMANCE

We have tested a group of 5 instruments over a period of approximately one year. The instruments under test were calibrated with reference to one of the units, which was arbitrarily chosen to be the standard detector. The gain of each instrument was set, on solar noon of a clear sky day, by adjusting it so that the output signal of the instrument agreed with the signal from the standard detector to better than 1 mV (0.4 mW/m$^2$ of effective UV-B irradiance). We monitored both the bobbin temperature and the output signal of the instruments. We found that the bobbin temperatures stay within ±0.1 °C of +45 °C even under the severest wind and temperature conditions of a New England winter. Accordingly, the output signals of the instruments track together with better than 1% accuracy in all weather conditions.

We have found an additional, unexpected, benefit to the use of heated, thermally stabilized detectors. On a number of occasions, on cold mornings, we noted that while unheated detectors would have frost or dew on the domes, the heated units had clear domes. Apparently, the small heat flux from the heated bobbin to the dome is sufficient to prevent frost and dew formation under most conditions.

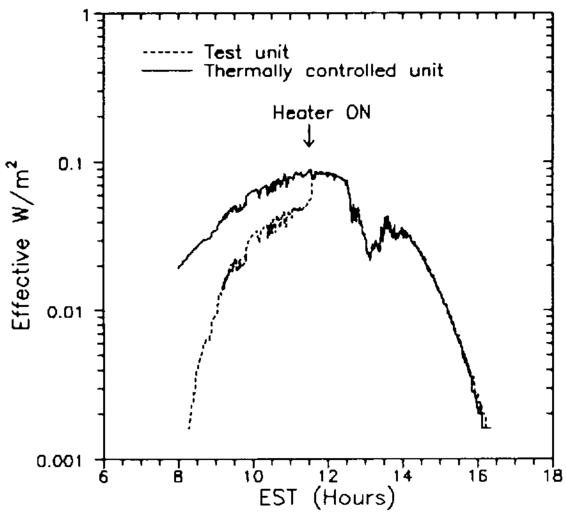


Figure 4. UV-B irrdiances measured by a thermally regulated instrument and an uregulated test unit.

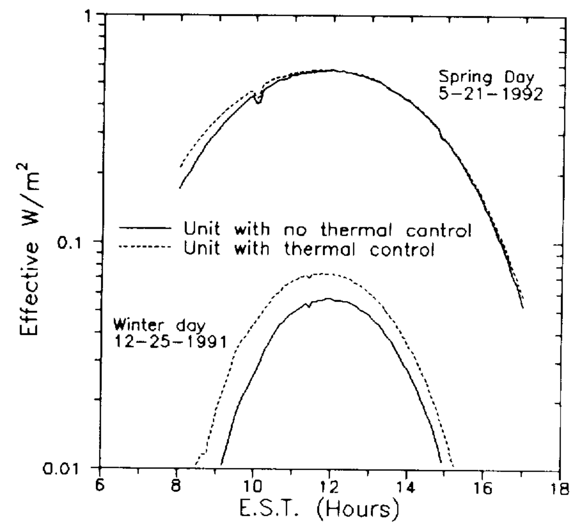


Figure 5. Comparison of output signals of a thermally regulated instrument and an unregulated one.

## 5. UV-B DOSE MEASUREMENT BIASES

Data collected from one thermally controlled and one uncontrolled instrument during a winter and a spring day (western Massachusetts location) are shown plotted in Figure 5. The ambient temperature was approximately 0 °C during the winter day, while for the spring day it peaked near +34 °C. It is evident that the difference between the signals from the two units is significantly different for the two days. The integrated dose for 5/21/1992 from the thermally uncontrolled instrument is 95.6% of the controlled instrument dose, while the winter day (12/25/1991) uncontrolled instrument dose is 71.5% of the controlled instrument dose. This effect can clearly lead to a seasonal bias when measuring UV-B using thermally uncontrolled $MgWo_4$ based detectors.

Most detectors are probably calibrated during the spring or summer, when solar UV-B irradiance is most intense. At that time, the ambient temperatures are high and the instrument calibration is fixed at a point where the phosphor temperature is also high. During the colder seasons, fall and winter, the phosphor is at a low temperature and the magnitude of its output signal drops (given an identical UV-B irradiance) relative to the warm phosphor output. Therefore, fall and winter UV-B levels, as measured by thermally uncontrolled Robertson-type detectors, may be significantly underestimated. In addition, uncontrolled instruments operating in colder climates will tend to record lower UV-B doses than similar instruments in warmer climates. This can lead to a geographical bias in global UV-B monitoring networks.

It should be noted that a similar effect would lead to underestimation of UV-B doses on cool summer and spring days. Conversely, the UV-B dose on warm winter days would be significantly overestimated. This type of an effect could lead to a spurious correlation between temperature, or some other atmospheric condition which affects temperature, and UV-B levels.

## 6. CONCLUSIONS

The thermal properties of the $MgWO_4$ phosphor lead to large temperature dependence of the output signal of Robertson type, broad band UV-B detectors. This dependence can lead to seasonal and geographical bias in the measurement of UV-B doses. We have developed and tested an instrument which incorporates thermal control of the $MgWO_4$ phosphor in its design. Results of field tests indicate that the thermal control feature has eliminated the temperature dependence of the output signal of the instrument. In view of the size of the possible thermally induced error in the measurement of UV-B, only thermally controlled instruments should be used in monitoring networks. If such instruments are not available, then ambient temperature must be monitored and recorded in order to correct the data collected by an uncontrolled instrument.

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