# Developing UV Monitoring with CCD Technology

Bruce W Forgan[1] and Peter McGlynn[2]

[1]Bureau of Meteorology, Docklands, Victoria, Australia
[2]RMIT, Melbourne, Victoria, Australia

**Abstract**. Two instruments for monitoring UV irradiance using single monochromator charge-couple detectors (CCD) array detectors have been developed for use within the Bureau of Meteorology's (BoM) Solar and Terrestrial Monitoring Network. The BoM has had some success in using CCD array detectors for monitoring direct solar spectral irradiance at visible and near infra red irradiance but the move to monitor UV required solving several significant issues, particularly the rapid rate of change in UV irradiance with wavelength and the strong stray light conditions typical of single monochromators. Two types of instruments were developed: a direct irradiance spectrometer (ASR-UV) and a 2$\pi$ sr radiometer (Pi-radiometer) for monitoring global and diffuse solar spectral irradiance. The instruments will be deployed in test phase in April 2010. The rationale for the basic design will be described as will the methods utilised to minimize the limitations of the use of a single monochromators and CCD technology.

## Rationale

The BoM maintains a five station network of Dobson spectrophotometers for monitoring total column ozone, these instruments are manually operated and began operation at the time of the International Polar Year in 1957. The BoM also operates a three station network of UV spectrometers: two based on the NIWA (McKenzie et. al., 1992; Bernhard et al., 2008) design at Alice Springs and Melbourne and one Optronics 704 system at Cape Grim. The only solar erythemal UV monitored by the BoM is also at Cape Grim.

Dobson spectrophotometers in the BoM network collect data between 3 and 4 times per day centred on solar noon, with the most accurate data provided by direct solar measurements; spectrophotometers measure ratios of irradiance and hence are not capable of monitoring spectral irradiance. The Dobson spectrophotometers are now over 60 years old and the expertise to maintain them is difficult to develop. Other spectrometers using scanning double monochromators for monitoring direct and global UV and hence deriving ozone exist but are expensive both in initial cost and on-going maintenance.

In 2000 The BoM designed and deployed a two direct spectral irradiance radiometers (ASR) utilizing small dual CCD array detectors with a spectral resolution of about 1.1 nm over the range 360-1000 nm. The devices enable traceability of the spectral irradiance to the World Radiometric Reference with a typical 95% uncertainty of 2% when the direct solar irradiance was greater than 700 Wm$^{-2}$, and are used for monitoring spectral transmission and deriving aerosol optical depth. The CCDs used in the instruments proved to be very stable with no change in sensitivity (at 25 °C) in 10 years of operation.

While stable these initial CCDs had characteristics that had to be determined before successful measurements could be attempted. The main characteristics apart from sensitivity were: (a) the zero signal was dependent on temperature and unique for each pixel; (b) the sensitivity of each pixel to solar exposure had a unique temperature coefficient; (c) the range of wavelengths meant that an order sorting system was required; (d) the detectors are non-linear; (e) there was a small shift in wavelength as a function of temperature; (f) stray light; and (g) dynamic range was limited.

However, since 2000 the development of CCD spectrometers continued with improvements in grating and detector combinations including at UV wavelengths, and filter technologies developed for LASER applications provided scope for stray light minimization.

As a result the BoM decided to investigate the use of CCD technology to replace its aging Dobson spectrometers for monitoring ozone and develop a small compact device for monitoring UV but with a simple design using as many off-the shelf components as possible.

## Design Concept

Two types of radiometer were developed: one modifying the existing ASR system for monitoring direct solar UV spectral irradiance, and another using the NIWA diffuser for monitoring global and diffuse solar UV solar spectral irradiance. The basic layout of the Pi-radiometers can be seen in Figure 1. The ASR differs from the Pi-radiometer by replacing the dual filter wheel with a single filter wheel and fixed UG11 filter that are both in front of the diffuser.

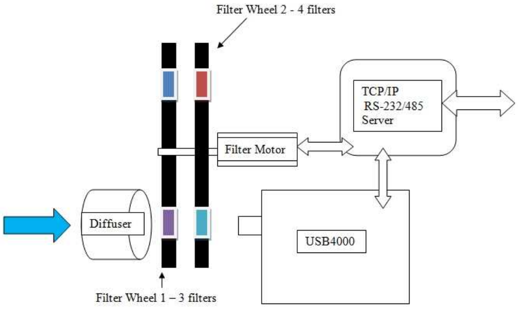

Figure 1. The schematic of the Pi-radiometer indicates that it communicates to the controlling PC via a dual port RS-232/485 interface via TCP/IP, with one port for the stepper motor and temperature monitoring channels and the other for the Ocean Optics[1] USB4000 spectrometer.

The Pi-radiometer's dual filter wheel has 3 filters in the 1st and 4 filters in the 2nd filter wheels allowing 12 potential combinations to isolate parts of the incoming spectrum and to assist with stray light elimination. The

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[1] Naming of the Ocean Optics product does not indicate Bureau of Meteorology endorsement.

ASR single filter wheel has 8 positions for filters. The two radiometers are shown in Figure 2.

Figure 2. On the left is the ASR deployed at Melbourne Airport, and on the right the Pi-radiometer, next to a CD-ROM to provide an indication of size.

Both the Pi-radiometer and ASR-UV configuration use a single Ocean Optics USB4000 UV-enhanced spectrometer with a 3640 pixel detector, a pixel width of 0.072 nm over an effective wavelength range of 265 to 490 nm, and a slit width of 50 μm, providing a typical resolution of 0.5 nm.

The filter position is determined by a high precision stepper motor, and position sensing element. Five temperature sensors are deployed to monitor the internal temperatures and those of the diffuser and outside temperature of the USB4000. The USB4000 also has in internal temperature monitor. The Pi-radiometer uses the same diffuser developed for the NIWA spectrometer.

The filter sequence and data acquisition is controlled by PC software using the TCP/IP connection to relay commands an receive data via the BoM wide area network. A full sequence of measurements with all valid filter positions is typically less than 3 minutes in duration.

## Resolving Technical Issues

(a) Zero signal variation with temperature.

There is no need to calculate zero signal levels as a zero blocked filter zero irradiance spectra are taken at the start and end of each measurement sequence and subtracted from irradiance spectra.

(b) Changes in sensitivity due to temperature

The spectrometers are placed in a thermal chamber and connected to a constant irradiance source. The spectrometers are then cycled through temperatures between 5°C and 45°C at 5°C increments and the temperature sensitivity for each pixel determined. The internal temperature of the USB4000 is used as the representative temperature.

(c) Order sorting

The small spectral range (250 nm) of the spectrometers has minimized order sorting issues.

(d) Non-linearity

Each spectrometer is provided with non-linearity coefficients by the manufacturer however these were found to be error prone at low and high count levels. The BoM performs its own non-linearity tests over the range of counts 200 to 32000 counts. The non-linearity is typically <2% over the entire range and quadratic in nature.

(e) Wavelength calibration

Laboratory tests have shown small <0.1 nm changes in wavelength over a 40°C range in temperature which can be modelled. However, as with NIWA spectrometer (McKenzie et. al, 1992) processing the wavelength adjustment of each scan will be undertaken using the structure of the solar output using the Fraunhofer lines.

(f) Stray light

Two methods are to be used to minimize stray light impact. The mathematical method detailed by Zong et. al. (2006) that uses mathematical inversion of LASER line response functions to provide a stray light irradiance corrected signal. The second method uses very sharp cut on LASER edge filters to allow transmission of irradiance at higher wavelengths where the dominant solar energy lies, hence at wavelengths shorter than the cut off, a standard spectrum minus the LASER line spectrum should provides a stray light reduced spectrum. Initial tests suggests that the latter method combined with a UG11 filter that transmits at wavelengths less than 400 nm provides significantly reduces stray light. Initial studies also indicate that a simple correlation with higher wavelength spectral counts (essentially an empirical inversion) may be also be satisfactory for all wavelengths > 300 nm.

(g) Decadal signal variation over 20 nm

The use of LASER edge filter at wavelength of 300 and 325 nm and different integration times will enable a combined spectrum to be produced from 3 or more separate measurements. As the increase in spectral irradiance is at longer wavelengths than UV the collection of saturation free spectra is straight forward and stray light is minimized.

Traceability of the UV measurement is through the use of NIWA compact lamp units that are calibrated on an regular basis.

## Future

The ASR UV will be collocated with the Melbourne Dobson spectrophotometer in early April 2010, and the UV Pi-radiometer collocated with the existing NIWA UV spectrometer at a Bureau test facility that is also in Melbourne. Four more UV Pi-spectrometer should be deployed in 2011. Adaption to a solar tracker capable will enable alternate global and diffuse measurements Wilson & Forgan, 1996).

The Pi-radiometer can also be configured for 350-1000 nm observations and one is expected to be deployed at the Alice Springs station in late 2011.

## References

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