Direct beam Irradiance Atmospheric Spectrometer (DIAS)

Instrument: NCAR Direct beam Irradiance Atmospheric Spectrometer (DIAS)
Principal Investigator: R. E. Shetter
Organization: Atmospheric Chemistry Division
National Center for Atmospheric Research
1850 Table Mesa Drive, Boulder, CO

The NCAR Direct beam Irradiance Atmospheric Spectrometer (DIAS) instrument is a scanning spectroradiometer to determine the direct solar ultra violet and visible irradiance from the NASA DC-8 aircraft during the SOLVE 2 mission. The direct beam irradiance data will be used to calculate the slant path ozone column and the wavelength dependent aerosol optical depth from 280 nm to 750 nm. The instrument is comprised of 3 subsystems: a narrow field of view optical collector, a microprocessor controlled 2-axis gimbal pointing system, and a scanning
double monochromator detection system. The instrument is represented schematically in Figure 1.

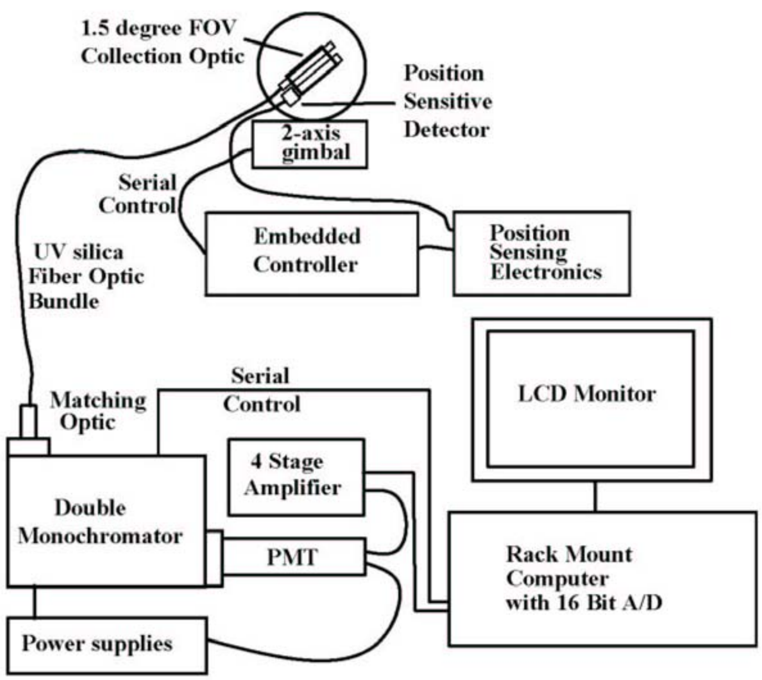

Figure 1.

The narrow field of view collection optic accepts the direct solar beam while excluding almost all of the atmospherically scattered radiation. While the entire solar disk could be sampled with a ~0.5° field of view, a 3.6° field of view allows for some inaccuracy or short time lags in the response of pointing system without inducing significant errors in the measurements. The collection optic is mounted to the pointing system at the center of rotation of the x-axis and y-axis and is optically connected to the detection system with a flexible UV fiber optic bundle.

The pointing system contains a commercially available 2-axis gimbal, a position sensing system, and a custom embedded controller system. The Sagebrush Technology Model-20 servo gimbal is compact and lightweight with a large range of motion. Positional resolution of 0.004° and angular travel rates up to 120° per second should provide excellent performance for aircraft applications. The gimbal is controlled by communication with RS-232 commands or a commercial grade joystick. The position sensing detector system consists of a focusing lens and a duolinear position sensing module (On-Track Photonics 2L4SP) mounted on the gimbal and a position sensing amplifier (On-Track Photonics OT-301) and readout system. The lens focuses the image of the solar disk on the position sensing detector and the amplifier produces x and y-axis voltages which are directly proportional to the image position on the detector. Changing solar intensity can be accommodated by addition of an optical filter and/or 6 amplifier gain ranges available on the amplifier module. The embedded controller system is based on a Motorola 68338 single board computer (Persistor CF-1). This low power computer is interfaced with a 4 channel 16-bit analog to digital card (OES AD16S) and a 4 port serial interface card (OES U4S) and can collect 4 channels of analog data and record data and times to a compact flash card. The controller will collect and store x and y-axis data from the position detection system, process the data with an internal program written in C code, and issue RS-232 commands to control the 2-axis gimbal.

The double monochromator detection system employs a fused silica fiber optic bundle, an f matching optic, an 1/8 meter scanning double monochromator (CVI CM112), a UV sensitive photomultiplier (EMI 9136QA), a custom 4 channel electrometer/amplifier, and a rack mount data acquisition and control system. This system is based on an instrument used by *Shetter and Müller* [1999] for wavelength dependent actinic flux measurements from aircraft. Except for the computer, all components of the instrument are enclosed in a 19 inch rack mountable box 17.8 cm high and 61 cm deep, that weighs 17 kg. The monochromator, photomultiplier tube, and amplifier are temperature stabilized at 312 K during calibration and field measurements. The FWHM of the CVI CM112 double monochromators is 1.0 nm using 2400 g/mm gratings and 600 micron entrance and exit slits and could be reduced to 0.5 FWHM by using 300 micron slits. This combination of gratings and slits produces a symmetrical triangular slit function. Since the intensity of the solar spectrum from the UV-B to the UV-A changes by 5-6 orders of magnitude, spectrometers with excellent stray light rejection are needed to make accurate UV-B measurements. The CVI monochromators have stray light rejection of $>10^9$ while the best single monochromators only achieve $<10^5$, therefore making accurate UV-B measurements difficult. Stray light rejection problems can be easily identified by comparing the signals in ambient ground based solar spectra in the 280-290nm region, where there is very little radiation, with the signals obtained for no solar input (instrument dark current). The stray light rejection performance of the monochromator allows the detection limit of the instrument to be based on the noise of the instrument dark signal and does not require a subtraction of a stray light signal. The photomultiplier is a quartz window EMI 9136QA with good quantum efficiencies from 260 to 750 nm with low dark currents. This response combined with the throughput of the monochromator allows for measurements from 280 to 750 nm.

The electrometer/amplifiers have four gain stages ranging from 10^5 volts/amp to 10^8 volts/amp. These four stages allow the analog to digital converter to always convert a voltage (above the limit of detection) in a range that utilizes the 16-bit resolution of the analog to digital converter regardless of the photomultiplier current. These gain ranges of the amplifiers were calibrated to insure linear instrument response over the 6-7 orders of magnitude of expected signals. The data acquisition and control system is based on a single board Pentium II computer, a National Instruments 16-bit data acquisition board, Bancomm IRIG-B time synchronization hardware and LabVIEW software. The IRIG-B hardware and software enables the instruments to be synchronized within 1 millisecond of other payload instrumentation. Similar detection systems have been deployed on the DC-8 for PEM Tropics A, SONEX, PEM Tropics B, SOLVE 1, and recently on TRACE P. These systems have worked quite well with data returns consistently at >95%.

Instrument calibration

Wavelength calibration
The monochromator wavelength assignment and instrument function are checked before and after each flight by referencing to a low pressure mercury lamp spectrum. Individual mercury lines covering the full UV-B, UV-A, and visible range will be used to determine how much the wavelength assignment of the monochromator differed from the nominal literature value. Wavelength calibration software controls the instrument to step 16 times over each single line with a step width of 0.1 nm. The average signal vs. wavelength is plotted and the center of the resulting triangular peak is calculated and the FWHM checked. If the calculated wavelength assignment differs significantly from the literature wavelength assignment an instrument adjustment is performed.

Absolute spectral calibration
The absolute spectral sensitivity of the instrument (optical collector, fiber, F# matching optics, monochromator, photomultiplier, amplifier, and data acquisition system) is calibrated in a laboratory optical calibration facility at 3 source-to-detector distances using 1000-watt NIST traceable quartz-tungsten-halogen lamps with uncertainties of 3-4%, depending on the wavelength. These primary laboratory calibrations will be performed before shipment for aircraft integration and after the instruments are returned from the field. In order to trace any possible drifts in instrument sensitivity, secondary spectral calibrations will also performed in the field before and after each flight, using 250-watt QTH calibration lamps mounted in a field calibration unit that will attach to the optical viewport mounting on the side of the aircraft. These secondary calibrations are linked to the primary calibrations by a series of “transfer” calibrations with the 250-watt lamps, which are performed in the laboratory before and after the deployment.

For the absolute calibration of the irradiance, the largest uncertainty arises from the calibration lamp certification (4.0 % in the UV-B range and 3.0 % in the UV-A/visible range). The uncertainty of the reproducibility of the geometrical conditions of the original calibration is estimated to be 1.5 %. The accuracy of the current output of the radiometric power supply is given by the manufacturer to be ±0.1 %, which results in an uncertainty of the UV-B intensity of 1.0 %. Depending on the shape of the tropospheric spectrum, the uncertainty of the wavelength calibration results in an uncertainty of the irradiance of about 2.0 % in the UV-B range and 0.5 % in the UV-A range. A number of parameters affect the reproducibility (precision) of the irradiance determinations. From the day-to-day variability of the calibrations during a mission as well as from the history of laboratory calibrations, we estimate the reproducibility of the calibration measurements to be approximately 2.0 %.

Instrument Operation

The system will work as follows: at the start of a flight the 2-axis gimbal will be controlled by the joystick to direct the solar disk image onto the position sensing detector, the embedded controller will take control and read the X and Y analog voltages from the position sensing subsystem, process the data with internal software, and send RS-232 positional commands to the 2-axis gimbal to center the solar disk image on the detector. As the aircraft has changes in direction, pitch or roll, the pointing system will adjust the azimuth and elevation to keep the solar image centered.

Once the pointing system has centered the solar image, the detection system will scan the UV-B, UV-A, and visible ranges from 280 to 750 nm in 1 nm discreet steps. In addition, wavelengths from 240 to 245 nm will be sampled during each wavelength scan to establish the instrument dark current. The instrument is capable of averaging multiple readings at each wavelength to statistically reduce instrumental noise. In previous configurations, between 100 and 800 samples were taken at each wavelength. Scan time for a full spectrum from 280-750 nm is expected to be approximately 30 seconds, dependent on number of readings per wavelength.

Shetter, R. E., and Martin Müller, **Photolysis frequency measurements on the NASA DC-8 during the PEM-Tropics Mission using actinic flux spectroradiometry: Instrument description and results**, *J. Geophys. Res.*, 104, 5647-5661, (1999).