APPENDIX VI - Ultraviolet Spectro-Radiometry

The instrument specifications and measurement strategy should be driven by the program goals. These are not necessarily the same as in other programs, such as those devised for the biological community (e.g., USDA), although it is envisaged that the NDACC UV data products would be applicable for such purposes. Here, the aims are:

- to understand the spectral consequence in the UV region of changing atmospheric composition (e.g., ozone, aerosols, clouds);
- to understand geographic differences in UV;
- to monitor long term changes in UV; and
- to make properly calibrated UV data available to the community.

Crucial to meeting these objectives is the availability of data from a wide range of NDACC instrumentation. However, supplementary measurements of the radiation field are also required. Advances in our understanding of these objectives will be achieved by relating measurements to model calculations.

A useful but ambitious goal would be to attempt to detect the change in UV that results from a 1% change in ozone. The primary interest is in UV increases resulting from reductions in ozone, but this criterion could include possible reductions in UV resulting from future recovery of the ozone layer, or from a build up of tropospheric pollution (e.g., aerosols, ozone).

Quality Criteria for the Evaluation of New Instruments and Instrument Teams

From past experience, it appears that the best absolute accuracy that can be maintained for instruments designed to measure solar UV irradiances is currently limited to a few percent (perhaps ±5%). Thus, to achieve the above goal, it will be necessary to include measurements at short wavelengths, where small changes in ozone lead to relatively large changes in UV.

The absolute and relative spectral changes in UV resulting from a 1% ozone depletion have been calculated for overhead sun and for SZA = 70^{m} [Madronich, S., Trends and predictions in global UV, in *The Role of the Stratosphere in Global Change*, M. L. Chanin, Editor, NATO ASI Series I: Global Environmental Change, Vol. 8, Springer-Verlag, Berlin, 463-471, 1993]. Percentage changes in UV increase rapidly at shorter wavelengths, but absolute changes decrease at wavelengths shorter than 310 nm. For overhead sun, a radiation change of 5% occurs at approximately 295 nm, when the absolute change in irradiance is approximately 10^{-4} W m^{-2} nm^{-1}. At larger SZA, the condition for a 5% change in irradiance occurs at longer wavelengths. However, the corresponding absolute changes are even smaller, and thus more difficult to detect. It should be noted that high-sun observations are not always possible. For example, at high latitudes in winter, where ozone and UV changes are expected to be largest, the minimum SZA becomes large and can exceed 90^{m}. These calculations show that given a calibration uncertainty of 5%, the increases in UV resulting from a 1% ozone depletion will be detectable only if the detection threshold is of order 10^{-6} W m^{-2} nm^{-1} (i.e., 10^{-4} mW cm^{-2} nm^{-1}), or better.

To detect a change at 295 nm, precise wavelength alignment is also required. A wavelength error of 0.1 nm corresponds to an irradiance error of approximately 4% for overhead sun conditions. Thus, wavelength alignment precision must be significantly better than ±0.1 nm.

There may be many ways of achieving the end point of accurate measurements of the spectral distribution of UV irradiance, e.g., choices between:

- Diffuser or integrating sphere (or other)
- Subtractive or additive dispersion
- Photomultiplier or diode array or CCD or other
- Constant or variable scan speed
- Gain switching or filtering or other
- Pulse counting or analog
- Etc.

These should not be prescribed, but minimum performance specifications must be met. Some aspects of data quality can sometimes be improved beyond the basic instrument limitations during data analysis. Examples of improvement methods follow.

- Wavelength alignment can be improved by correlation alignment.
- Deconvolution can improve the bandwidth.
- Cosine error correction can improve accuracy of absolute irradiances.

Consequently, specifications are given in terms of final data quality desired (see following table). Clearly some improvements would be achieved by averaging of the spectra.

Quality Criteria for the Evaluation of Continuing Instruments and Instrument Teams

The Investigator has primary responsibility for ensuring the quality of data from the instrument on a continuing basis, and for submitting the data to the NDACC archive in a timely manner. The following table should be met. The specifications are given in terms of final data quality desired. Clearly some improvements would be achieved by averaging of the spectra.

UV Spectral Irradiance Data Specifications*

From: McKenzie, R. L., P. V. Johnston, and G. Seckmeyer, UV spectro-radiometry in the network for the detection of stratospheric change (NDACC), in *Solar Ultraviolet Radiation. Modelling, Measurements and Effects, Halkidiki, Greece, 1.52*, edited by C. S. Zerefos and A. F. Bais, pp. 279-287, Springer-Verlag, Berlin, 1997.

Quantity	**Quality**
Cosine response error	< ±5% to isotropic irradiance, and for all angles < 60^{m} from the zenith
Minimum spectral range	> 290 - 400 nm
Band width (fwhm)	< 1 nm
Wavelength alignment	< ±0.03 nm (precision) < ±0.05 nm (absolute accuracy)
Slit function	< 10^{-3} of max. 2.5 x fwhm from line center < 10^{-5} of max. 6.0 x fwhm from line center
Sampling step interval	< 0.5 x fwhm
Saturation threshold	> 1.5 W m^{-2} nm^{-1} (noon max. at 400 nm)
Detection threshold	< 10^{-6} W m^{-2} nm^{-1} (for S/N = 1 at 1 nm fwhm)
Scan time	< 10 min
Overall calibration accuracy	< 5% (unless limited by threshold)
Stray light	As defined by the detection threshold
Temperature	Monitored, and with stability sufficient to maintain overall stability (typical T-stability < ±2 K)
Scan date and time	Recorded with each spectrum (so that timing is known to within ±10 s at each wavelength)
Diffuse/direct measurements	Capability of distinguishing each component.

(*) Note that some instruments already in use may not meet all of the above requirements, but may still provide unique and useful information. Furthermore, it is possible by accumulating measurements (wavelengths and times) to improve the accuracy. It may therefore be appropriate for the NDACC committee to be able to exercise some discretion in accepting data for its archives that depart from these specifications. However, the data specifications should be specified in terms of the above criteria, and must be auditable.

Required Ancillary Measurements

- Ozone total column
- R-B type meter
- Broadband pyranometer
- Direct irradiance (normal incidence) pyranometer

Desirable Ancillary Measurements

- Atmospheric pressure
- Profiles of ozone
- Profiles of aerosols (lidar or backscatter sonde)
- Trace gases (NDACC)
- Cloud images
- Illuminance meter
- Record intensity change during scans
- Aerosol optical depth
- Surface albedo

Data Frequency

- Sufficient scans to enable an accurate daily integral to be found on days with no rain (e.g., at set intervals in SZA, or time).
- If timing intervals are used, then sufficient scans to enable interpolation to fixed sun angles.
- Including scans at local solar noon.
- All weather, automated.

Data Processing

- Wavelength alignment precision to 0.03 nm
- Capability of cosine corrections
- Capability of quantifying intensity changes during scan

Calibration and Archival

All calibration information must be auditable. Calibration information 'metadata' must be archived at the observation site.

Irradiance and Wavelength

Daily:

- Ozone retrieval
- Dark current offset tests.

Weekly/monthly:

- Stability tests of irradiance sensitivity (e.g., lower wattage Quartz-halogen lamp)
- Model calculation to check wavelength alignment
- Hg lamp: bandpass, wavelength alignment and stray light.

Yearly (or as required):

1. Standard lamp calibration, traceable back to national standards laboratory (NIST, NPL, PTB, ...) in no more than two steps. Each step removed from standards lab adds uncertainty in the transfer of the standard. To avoid escalation of errors from this source, we specify that our lamps are no worse than secondary standards with respect to the National Laboratories.

   Accuracy of calibrations, to standards specified in NIST guidelines for 1000-W lamps, noting that variations in lamp current of 1% result in UV irradiance variations exceeding 10%. Careful attention must be paid to setting up:

   - Distance
   - Orientation
   - Current sense (constant)
   - Current magnitude monitored by voltage drop across a precision resistor calibrated by standards lab (10-5 precision and 10-4 accuracy),
   - Room temperature (stable and monitored).

   Maintenance of Calibration Standards

   - 1000-W lamp must be recalibrated at an approved standards lab (or replaced) after 20 hours lamp use.
   - Shunt Resistor recalibrated at least every two years (keep two on site)
   - Precision DVM recalibrated at least every two years (keep two on site)

2. Cosine response errors must be characterized by laboratory tests in at least two planes.

3. Electronic linearity and offsets (e.g., double-aperture tests).

4. Stray light tests

   - ‘Near-field stray light - Check that contribution within a few nanometers of a spectrally pure source (e.g., HeCd 325-nm laser line or Hg 254-nm) satisfies the specification.

   - Far-field stray light - In stable, clear sky conditions near noon, select a wavelength (e.g., 300 nm) where the irradiance is approximately 100 times larger than the detection threshold, so that its signal can be measured to 1% accuracy. Place a suitable Schott Glass filter (e.g., WG 320) over the entrance aperture to block radiation at the selected wavelength, and to transmit only longer wavelengths. Any remaining signal (after removal of electronic and thermal offsets) is then due to stray light leakage (attenuated by visible reflection losses at the surfaces of the filter, typically 8% (4% at each surface)).

Other Quality Control Procedures

Regular intercalibrations should be performed with the following:

- Other NDACC quality instruments (if available)
- Traveling lamp standard (if available)
- Traveling instrument standard (if available)
- Calibration against other sources (e.g., the Synchrotron Ultraviolet Radiation Facility (SURF) at Gaithersburg, or black body of PTB)
- Time series of broadband data (e.g., R-B meter) at same site.

Regular analysis of the data in research mode will identify potential problems at an early stage.

Maintain a log book of instrument changes, lamp and calibration details.

Data Archival

Raw Data: Archive, including calibration files on site.

Processed Data: Preliminary summaries to be archived rapidly NASA/AMES format

Spectral data available from PI (~20 - 100 Mbytes/year). In our experience, significant improvements can sometimes be achieved by reprocessing UV spectral data after instrument problems have been identified.

Changes in Instruments and Data Analysis

Since one of the major goals of the NDACC is the detection of long-term trends, care should be used in any modifications of the instrument or data analysis which may affect the results. Once the regular operation of an instrument has begun, such changes should not be undertaken lightly; consultation with the Ultraviolet-B Working Group (UV-BWG) is recommended. The primary data (interferograms or spectra) should be retained by the Investigator indefinitely (although not deposited in the NDACC archive), so that improved data-retrieval processes, including improved spectral line parameters, can be applied retrospectively to the earlier data. In such cases, the entire dataset should be reprocessed and archived, along with (at least) reference to earlier versions.

Version: March 24, 2009

Sample Data File on NDACC Archive (first few scans only from one month of data)

```
56  1010                                          {NLHEAD  FFI}
McKenzie, Richard L.
NIWA Lauder, New Zealand
UV spectral irradiance at Lauder New Zealand (UVL Instrument based on JY DH10)
NDACC
1  1                                              {IVOL  NVOL}
1994   1 31    1994   2  28                       {DATE, RDATE}
0
Day of Year including decimal fraction (ddd.ddd). Noon on 1 Jan =1.5
15                                                {NV}
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
9.9E+9 9.9E+9 9.9E+9 9.9E+9 9.9E+9 9.9E+9
9999.9 9999.9 9999.9 9999.9 9999 9999 99.9 9.99 999
290-450 nm integral(W m-2)
315-400 nm UVA     (W m-2)
290-315 nm UVB     (W m-2)
DNA-weighted UV    (W m-2), Green et al., 1975 formulation of Setlow, 1974
Erythemal UV       (W m-2), CIE according to McKinlay and Diffey, 1987
Generalised Plant  (W m-2), Green et al., 1974 formulation of Caldwell 1971
UVILM  International light monitor      (mV)*  Nominally mV/500  for Wm-2(Ery)
UVYES  Yankee Environmental Systems     (mV)*  Nominally mV/714  for Wm-2(Ery)
UVSLC  Solar light Co Biometer model 501(mV)*  Nominally mV/429  for Wm-2(Ery)
EPPLEY Total irradiance pyranometer     (mV)*  Nominally mV/4.27 for Wm-2
Supplementary diode mean value          (Counts logged, with 1 count=2.443 mV)
Supplementary diode standard deviation  (Counts logged, with 1 count=2.443 mV)
Instrument temperature (C)
Wavelength shift which has been applied to align with reference spectrum (nm)
Derived ozone amount (Du)
11
1 1 1 1 1 1 1 1 1 1 1
9999 99 99 99 99 999.9 9 9 999.99 999.99 9999
Year       (yyyy) All times UT
Month        (mm)
Day of month (dd)
Hour         (hh)
Minute       (mm)
Solar zenith angle at scan centre (degrees)
Source identifier (1=sun+sky, 2=sky only, 5-8 calibrations)
Sky flag          (1 for clear sky positive, else 0)
Station  latitude (degrees)
Station longitude (degrees)
Station elevation (m)
0
12                                                 {NNCOML}
Summary of Cosine-weighted UV spectral irradiances (Preliminary)
measured at the surface.
Full spectral data at 1 nm resolution (800 samples between 290 and 450 nm)
is also available on application   Input File: UVL94FEB.DAT
Note: * Marked sensors (ILM, YES, SLC, EPPLEY) not always available
e-mail: mckenzie@kea.lauder.cri.nz, ph: 64-3-4473-411, fx: 64-3-4473-348
Reference: McKenzie et al., Applied Optics 31, 30, 6501-6509, 1991
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DECDAY  *Date and Time*   SZA    S SkyFlag Lat  Long   Elev
        290-450nm  UV-A   UV-B   UVDNA   UVEry      UVPlant  (all in Wm-2)
        UVILM      UVYES  UVSLC  EPPLEY  Diode_mean & Stdev  Temp Shift Ozone
*****************************************************************************
 31.858 1994  1 31 20 36  60.0  1 0 -45.04   169.68      370
       6.40E+01 2.65E+01 4.82E-01 2.50E-02 6.07E-02 6.67E-02
            199      424      228     2595      415        2  35.3 -0.08  271
 31.878 1994  1 31 21  5  55.0  1 0 -45.04   169.68      370
       7.66E+01 3.21E+01 6.82E-01 4.02E-02 8.58E-02 1.05E-01
            298      606      333     3029      495        3  35.6 -0.06  268
 31.899 1994  1 31 21 34  50.0  1 0 -45.04   169.68      370
       9.09E+01 3.82E+01 9.07E-01 5.94E-02 1.15E-01 1.50E-01
            430      816      454     3474      577       11  35.9 -0.04  270
 31.919 1994  1 31 22  4  45.0  1 0 -45.04   169.68      370
       9.45E+01 4.16E+01 1.12E+00 8.21E-02 1.45E-01 2.01E-01
            566     1002      562     3690      627       17  36.1 -0.05  263
 31.942 1994  1 31 22 36  40.0  1 0 -45.04   169.68      370
       9.47E+01 4.18E+01 1.29E+00 1.03E-01 1.69E-01 2.43E-01
            703     1145      651     3605      638       15  36.3 -0.03  262
 31.967 1994  1 31 23 13  35.0  1 0 -45.04   169.68      370
       9.35E+01 4.08E+01 1.33E+00 1.14E-01 1.77E-01 2.62E-01
            784     1199      691     3402      621       10  36.4 -0.02  264
 32.010 1994  2  1  0 15  29.0  1 0 -45.04   169.68      370
       1.28E+02 5.58E+01 1.82E+00 1.68E-01 2.48E-01 3.70E-01
           1206     1701      983     4913      844        7  36.6 -0.01  272
 32.021 1994  2  1  0 30  28.3  1 0 -45.04   169.68      370
       1.24E+02 5.44E+01 1.81E+00 1.68E-01 2.47E-01 3.71E-01
           1199     1682      977     4750      826        4  36.8 -0.01  269
 32.031 1994  2  1  0 45  27.9  1 0 -45.04   169.68      370
       1.30E+02 5.65E+01 1.86E+00 1.75E-01 2.56E-01 3.85E-01
           1255     1758     1019     5011      863        8  36.9 -0.01  269
 32.075 1994  2  1  1 48  30.0  1 0 -45.04   169.68      370
       1.26E+02 5.56E+01 1.78E+00 1.62E-01 2.42E-01 3.61E-01
           1172     1685      968     4911      847        7  37.1 -0.01  272
 32.108 1994  2  1  2 36  35.0  1 0 -45.04   169.68      370
       1.18E+02 5.18E+01 1.58E+00 1.35E-01 2.12E-01 3.10E-01
            971     1493      849     4633      796        2  37.5  0.03  272
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