Appendix VI- Ultraviolet Spectroradiometry

The specifications and measurement strategy for NDACC spectral UV instruments are driven by the goals of the network < http://www.ndsc.ncep.noaa.gov/ >, which are not necessarily the same as those of other programs, such as those devised for the biological community (e.g., by the U.S. Department of Agriculture, USDA). However, NDACC UV data products would also be applicable for such purposes. The main objectives of spectral UV radiation measurements within the framework of NDACC are:

- to understand the spectral consequence in the UV region of changing atmospheric composition (e.g., clouds, ozone, aerosols);
- to understand geographic differences in UV radiation;
- to monitor long-term changes in UV radiation;
- to relate these changes to climate change;
- to validate UV data products derived from satellite observations;
- to validate the results of radiative transfer models and to improve such models; 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 (e.g., instruments to measure the vertical distribution of trace gases and aerosols), which complement spectral UV radiation measurements. Supplementary measurements of the angular distribution of the radiation field are also highly desirable. By relating measurements to model calculations, our understanding of UV radiation at the Earth’s surface and the factors driving UV changes can be advanced.

A useful but ambitious goal would be to detect the change in UV radiation resulting from a 1% change in total column ozone. Historically, a primary interest of NDACC was the detection of UV increases resulting from reductions in ozone. Now, with the Montreal Protocol being effective, the emphasis is on the establishment of a UV climatology and to investigate the various direct and indirect effects caused by climate change. An additional objective is the detection of changes in UV radiation caused by changes in tropospheric pollution (e.g., aerosols, ground-level ozone).

Quality Criteria for the Evaluation of New Instruments and Instrument Teams

From past experience, it appears that the lowest uncertainty 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 objectives, it is 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 irradiance resulting from a 1% ozone depletion have been calculated for overhead sun and for a solar zenith angle (SZA) of 70° [Madronich, 1993] . Percentage changes in UV increase rapidly at shorter wavelengths. 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°. With a calibration uncertainty of 5%, increases in UV resulting from a 1% ozone depletion will be detectable only if the detection threshold is on the order of 10^{-6} W m^{-2} nm^{-1} (i.e., 10^{-4} **μ**W cm^{-2} nm^{-1}), or better.

To detect a change at 295 nm, precise wavelength alignment is also required. At this wavelength, 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.

The technology of UV spectroradiometers is not prescribed but minimum performance specifications must be met to comply with the goals of UV spectroradiometry within NDACC. Some aspects of data quality can sometimes be improved beyond the basic instrument limitations during data analysis.

Quality Criteria

The principal 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 Data Host Facility in a timely manner. Specifications provided in the following table should be met. These specifications are given in terms of final data quality desired. Random errors (e.g., detection noise at small wavelengths) can be reduced by the averaging of spectra.

UV Spectral Irradiance Data Specifications*

The following specifications are adapted from McKenzie et al. [1997]:

Quantity	**Specification**
Cosine response error	< ±5% to isotropic irradiance, and for all angles < 60° from the zenith
Minimum spectral range	> 290 - 400 nm
Bandwidth (fwhm)	< 1 nm
Wavelength alignment	< ±0.03 nm (precision) < ±0.05 nm (absolute accuracy)
Slit function	< 10^{-3} of maximum 2.5 x fwhm from line center < 10^{-5} of maximum 6.0 x fwhm from line center
Sampling step interval	< 0.5 x fwhm
Saturation threshold	> 1.5 W m^{-2} nm^{-1} (noon maximum 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 detection threshold)
Stray light	As defined by the detection threshold
Temperature	Monitored, and with stability sufficient to maintain overall stability (typical temperature 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 to improve the accuracy by accumulating measurements (wavelengths and times). It may therefore be appropriate for the NDACC Spectral UV Instrument Working Group and the NDACC Steering 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.

These NDACC specifications are essentially identical to the specifications of S-2 instruments defined by the World Meteorological Organization (WMO) and described by Seckmeyer et.al. (2001).

Desirable Ancillary Measurements

- Total ozone column
- Broadband UV meter with erythemal response
- Pyranometer to measure total irradiance (wavelength range of 300 - 3,000 nm)
- Pyrheliometer to measure total direct (normal incidence) irradiance
- Atmospheric pressure
- Profiles of ozone
- Profiles of aerosols (lidar or backscatter sonde)
- Trace gases (e.g., provided by NDACC)
- Cloud images
- Illuminance
- Record intensity change during scans
- Aerosol optical depth
- Surface albedo

Data Frequency

- Data frequency should be sufficiently large to allow the calculation of accurate daily UV doses for days with no rain. Measurements should be performed as often as possible, but may also be executed at set SZAs or time intervals.
- If time intervals are used, data frequency must be high enough to allow interpolation to fixed SZAs.
- A scan at local solar noon should be available.
- Measurements should be automated and performed during all weather conditions.

Data Processing

- Capability to achieve a wavelength alignment precision of at least ±0.03 nm,
- Capability of cosine-error correction,
- Capability of quantifying irradiance changes during scan.

Archival of Calibration Information
All calibration information must be auditable. Calibration information 'metadata' must be archived at the observation site. Off-site archival is encouraged.

Quality Control

Daily:

- Ozone retrieval,
- Dark current offset tests.

Monthly (or as required):

- Stability tests of the spectroradiometer's responsivity (e.g., by using a low-wattage quartz-halogen lamp),
- Model calculation to check wavelength alignment,
- Determination of bandpass, wavelength alignment, and stray light, e.g. by using a mercury lamp.

Yearly (or as required):

Calibration with a standard of spectral irradiance (typically a 1000-W FEL lamp) that is traceable to a national standards laboratory[1] in no more than two steps. (Each step removed from a standards laboratory adds to the calibration uncertainty.). To ensure the accuracy of calibrations, procedures should follow recommendations published by standards laboratories for FEL lamps [e.g., Walker, 1987]. Careful attention must be paid to the setup of standard lamps considering:
Distance between lamp and entrance optics of UV spectroradiometer,

- Lamp orientation,
- Lamp polarity,
- Lamp current (current should be measured by the voltage drop across a precision resistor calibrated by a standards laboratory. The current should have a precision of 10^{-5} and an accuracy of 10^{-4}. This level of accuracy is required because variations in lamp current of 1% may result in UV irradiance variations of up to 10%.),
- Room temperature (stable and monitored).

Maintenance of Calibration Standards:

The primary standard of spectral irradiance (typically a 1000-W FEL lamp) should be replaced or recalibrated by a national standards laboratory (or a laboratory accredited by a national laboratory) after 50 hours of use. Because of the high cost of primary standards and the long lead time for obtaining

[1] For example, National Institute of Standards and Technology (NIST) in the United States; National Physical Laboratory (NPL) in England; Physikalisch-Technische Bundesanstalt (PTB) in Germany.

such standards, secondary standards may be calibrated by the NDACC investigator from the primary standard, and these secondary standards should be used for calibrating the UV spectroradiometer. The scale of spectral irradiance of secondary standards should be verified with the primary standard at least annually.

- Shunt resistors for measuring the lamp current should be recalibrated at least every two years (two resistors should be kept on site),
- Voltmeters for measuring the voltage across these shunts should be recalibrated at least every two years (two voltmeters should be kept on site).

The characterization of cosine response errors should be verified by laboratory tests in at least two planes. Electronic linearity tests should also be performed.

Stray light tests should include:

- 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 line) satisfies the specification.
- Far-field stray light: use the following procedure. For 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 that blocks radiation below the selected wavelength, and transmits only at longer wavelengths. Any remaining signal (after removal of electronic and thermal offsets) is due to stray light leakage (reflection losses at the surfaces of the filter are typically 8%; 4% at each surface).

Other Quality Control and Quality Assurance Procedures

To ensure the quality of measurements from a new UV spectroradiometer joining NDACC, measurements of the candidate instrument must be compared with a UV spectroradiometer that is already NDACC-certified. Results of the comparison are reviewed by NDACC's Spectral UV Instrument Working Group and the NDACC Steering Committee before data are acceptable for archiving in the NDACC Data Host Facility.

To ensure that the quality of measurements from an NDACC-certified UV spectroradiometer does not degrade over time, the instrument should be regularly intercompared with other NDACC-certified instruments. Additional quality assurance measures may include:

- the comparison of standard lamps maintained by other members of the NDACC Spectral UV Working Group, and

- the comparison spectroradiometric data with measurements by broadband instruments (e.g., UV meters with erythemal response) that are co-located with the UV spectroradiometer.

Calibration against other sources (e.g., the Synchrotron Ultraviolet Radiation Facility (SURF) at NIST in Gaithersburg, MD, or black body of PTB) is encouraged.

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

A logbook of instrument changes, lamp, and calibration details should be maintained.

Data Archival

- Raw Data: Archive on and off site, including calibration files.
- Processed Data: Archive spectral measurements on and off site. Data summaries (e.g., data products such as UV-A, UV-B, erythemal, DNA-weighted irradiance) have to be submitted to the NDACC Data Host Facility in a timely manner (e.g., at least annually) in NASA/AMES format. See an example data file at the end of this document.

When serious instrument problems have been identified, data should be reprocessed and resubmitted to the NDACC Data Host Facility.

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 that may affect the results. Once the regular operation of an instrument has begun, such changes should not be undertaken lightly; consultation with NDACC's Spectral UV Instrument Working Group is recommended. The primary data should be retained by the investigator indefinitely, 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 a reference to earlier versions.

References

Madronich, S., Trends and predictions in global UV, in *The Role of the Stratosphere in Global Change*, edited by M. L. Chanin, NATO ASI Series I: Global Environmental Change, Vol. 8, Springer-Verlag, Berlin, pp. 463-471, 1993.

McKenzie, R. L., P. V. Johnston, and G. Seckmeyer, UV spectroradiometry in the Network for the Detection of Stratospheric Change (NDSC), in *Solar Ultraviolet Radiation. Modeling, Measurements and Effects,* edited by C. S. Zerefos and A. F. Bais, NATO ASI Series I: Global Environmental Change, Vol. 52, pp. 279-287, Springer-Verlag, Berlin, 1997.

Seckmeyer G., A. Bais, G. Bernhard, M. Blumthaler, C. R. Booth, P. Disterhoft, P. Eriksen, R. L. McKenzie, M. Miyauchi, and C. Roy, *Instruments to measure solar ultraviolet radiation, part 1: spectral instruments*, WMO-GAW report No. 125, WMO TD No. 1066, World Meteorological Organization, Geneva, Switzerland, 2001.

Walker, J. H., R. D. Saunders, J. K. Jackson, and D. A. McSparron, *Spectral irradiance calibrations*, National Bureau of Standards, US Department of Commerce, Vol. 250, No. 20, Gaithersburg, MD, 1987.

Version: March 21, 2017

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
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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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