# 6. Cooperative Programs

## UV Spectroradiometer Monitoring Program: Influence of Total Ozone, Cloud Cover and Surface Albedo on UV Doses in Barrow, Alaska

G. BERNHARD, C.R. BOOTH, J.C. EHRAMJIAN, S.A. LYNCH, AND V.V. QUANG
*Biospherical Instruments Inc., San Diego, California 92110-2621*

### INTRODUCTION

The United States National Science Foundation's (NSF) Ultraviolet Spectroradiometer Monitoring Network for Polar Regions was established in 1988 to collect data on the consequences of ozone depletion. The network currently consists of several automated, high-resolution spectroradiometers (Table 1). Three network stations are located in Antarctica, including the CMDL site at the South Pole Station (SPO). Another instrument is deployed close to the CMDL facility in Barrow, Alaska (BRW). Additional instruments are located in Ushuaia, Argentina, and San Diego, California; the latter serves as a training and testing facility. Finally, a portable system is available for instrument intercomparisons. Now in its thirteenth year of operation, the network continues to make measurements of ultraviolet (UV) spectral irradiance and provides a variety of data products to quantify biologically relevant UV exposures. Biospherical Instruments Inc. is responsible for operating and maintaining the network and distributing data to the scientific community.

The network is equipped with Biospherical Instruments Inc. Model SUV-100 spectroradiometers. Each instrument contains a double monochromator with holographic gratings and a photomultiplier tube detector. A vacuum-formed Teflon diffuser serves as an all-weather irradiance cosine collector. All systems are temperature stabilized for optimum radiometric stability. Spectra are sampled automatically every 15 minutes between 280 and 600 nm with a spectral bandwidth of 1.0 nm full width at half maximum. Tungsten-halogen and mercury vapor calibration lamps are used for daily automatic internal calibrations of both responsivity and wavelength registration. All instrument functions, calibration activities, and solar data acquisition are computer controlled. Further details on the spectroradiometers are described by *Booth et al.* [1994, 2000].

### UV RADIATION CLIMATE AT THE SPO AND BRW NETWORK INSTALLATIONS

This report focuses on data from the CMDL facilities at the SPO and BRW network installations. The SPO site is characterized by very high surface albedo throughout the year. Clouds are usually thin and clear sky days are relatively frequent. Because of the stable weather conditions, the high air purity, and high latitude, SPO is an ideal place to study the influence of variations in total column ozone on UV irradiance [*Booth and Madronich*, 1994].

The conditions at BRW are quite different from SPO. Cloud cover is highly variable, and significant changes in surface albedo occur because of both the springtime snowmelt [*Dutton and Endres*, 1991] and changes in sea ice coverage. Also, Barrow experiences significant changes in incident irradiance because of Arctic storms.

Figure 1 contrasts the radiation pattern of both sites. Time-series of integrated spectral irradiance at local solar noon are depicted for two wavelength bands covering 1991-1999. One spectral band (Figure 1a) represents DNA-weighted irradiance calculated from measured solar spectra and the action spectrum for DNA damage suggested by *Setlow* [1974]. DNA-weighted irradiance has a high contribution from wavelengths in the UV-B and is, therefore, very sensitive to changes in atmospheric ozone concentrations. The other band (Figure 1b) is spectral irradiance in the visible part of the spectrum, integrated between 400 and 600 nm. From Figure 1b it is evident that visible radiation at SPO shows little variation from year to year. Moreover, irradiances in this wavelength band are usually close to the envelope formed by the clear-sky level, confirming that cloud influence at SPO is small. In contrast, irradiances in the 400-600 nm band at BRW show a high variability because of day-to-day changes in cloud cover. The cloud influence is clearly more pronounced in the second part of the year. Because of the difference in latitude, radiation levels in the visible part of the spectrum are usually lower at SPO than at BRW.

TABLE 1. Installation Sites

| Site | Latitude | Longitude | Established | Location |
|---|---|---|---|---|
| South Pole | 90º00'S | - | February 1988 | ARO* |
| McMurdo Station | 77º51'S | 166º40'E | March 1988 | Arrival Heights |
| Palmer Station | 64º46'S | 64º03'W | May 1988 | T-5 Building |
| Ushuaia, Argentina | 54º49'S | 68º19'W | November 1988 | CADIC† |
| Barrow, Alaska | 71º18'N | 156º47'W | December 1990 | UIC-NARL‡ |
| San Diego, California | 32º45'N | 117º11'W | October 1992 | Biospherical Instruments Inc. |

*ARO: Atmospheric Research Observatory, system relocated to this new, joint NSF/CMDL facility in January 1997.
†CADIC: Centro Austral de Investigaciones Cientificas, Argentina.
‡ UIC-NARL: Ukpeagvik Inupiat Corporation-Naval Arctic Research Laboratory.

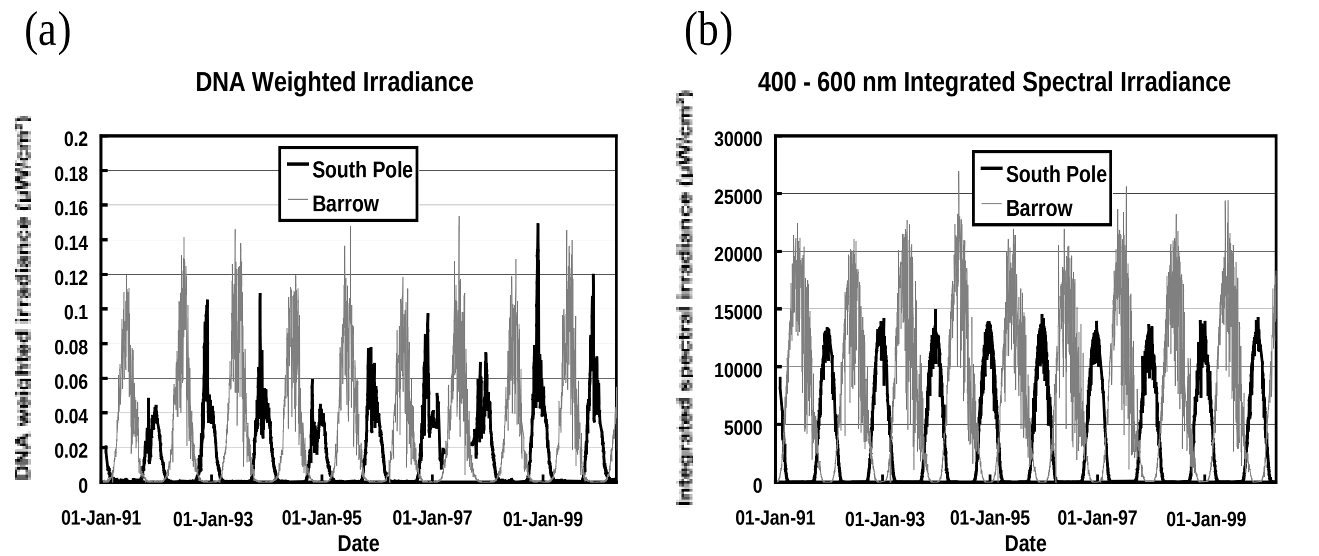


Fig. 1. Local solar noontime integrated spectral irradiance at South Pole and Barrow for 1991-1999: (a) DNA-weighted irradiance and (b) visible irradiance (400-600 nm integral). Note that 1999 data are preliminary and subject to revision.

In contrast to visible radiation, DNA-weighted irradiance at SPO (Figure 1a) shows high day-to-day fluctuations because of the ozone influence. For example, the peak in DNA-weighted irradiance observed at SPO in late November 1998 is due to extraordinarily low total column ozone values and the comparatively high solar elevations prevailing during this part of the year.

## Influence of Ozone, Cloud Cover, and Albedo on Radiation Doses in Barrow

Figure 2 shows daily doses calculated from both DNA-weighted irradiance data and irradiance measurements in the 400-600 nm band. In order to remove year-to-year variability, both doses were averaged over 1991-1997.

The average daily DNA-weighted dose is quite symmetrical with respect to the solstice (June 21) (Figure 2). The average daily dose in the visible band, however, appears to be shifted by approximately 14 days towards spring. Figure 3 shows this asymmetry more clearly. Here, both doses of Figure 2 were mirrored at the solstice, and the ratio of spring-to-fall values was calculated. The resulting ratios depicted in Figure 3 are, therefore, independent from solar zenith-angle dependence and normalized to 1 at the solstice. Average doses in the 400-600 nm band appear to be a factor of 2 higher in spring than in fall. DNA-weighted doses, on the other hand, do not show a clear spring-fall asymmetry.

The spring-fall ratio for the DNA-weighted dose derived from the measurements was compared with analogous ratios that were computed from the expected influence of ozone, cloud cover, and surface albedo on the DNA-weighted dose (Figure 4). Line 1 in Figure 4 is identical to the measured DNA ratio in Figure 3. Line 2 reflects the spring-fall DNA ratio that would be expected if the seasonal cycle in total column ozone was the only parameter affecting the DNA dose. This curve was calculated with Total Ozone

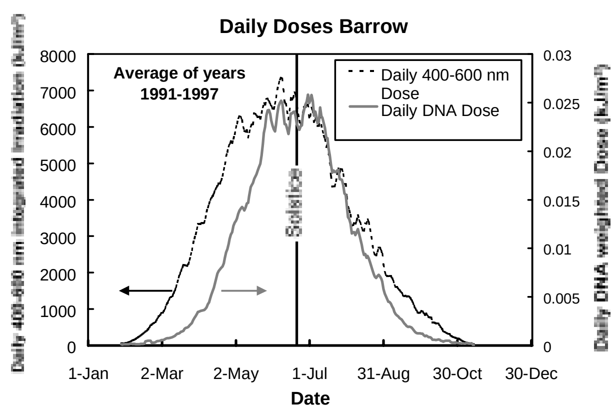


Fig. 2. Daily doses at BRW averaged from 1991-1997. The dashed line (left axis) is the average daily dose in the 400-600 nm band; the solid line (right axis) is average daily DNA-weighted dose.

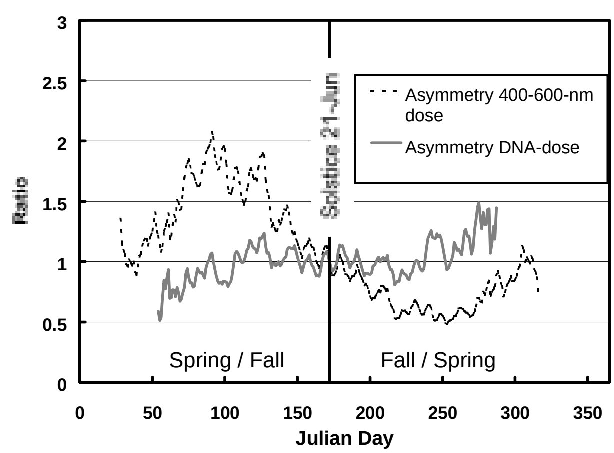


Fig. 3. Spring-fall asymmetry of the radiation doses in BRW. The dashed line is the spring-fall ratio for the 400-600 nm dose; the solid line is the analogous ratio for DNA-weighted dose.

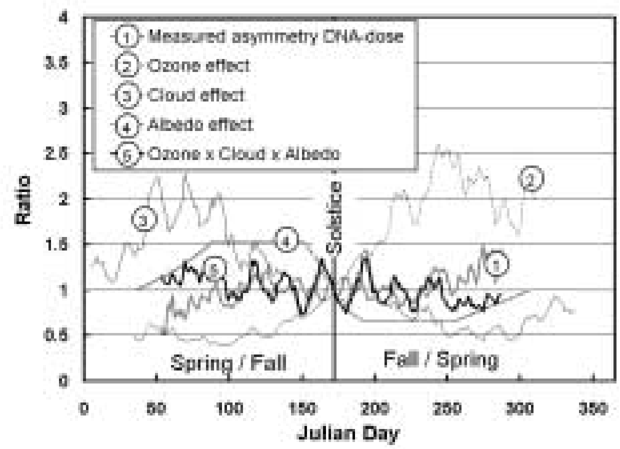


Fig. 4. Explanation of spring-fall differences in the average daily DNA-dose at BRW. Line 1: Measured spring-fall ratio of the DNA-dose. Line 2: Expected spring-fall ratio from the annual cycle in total column ozone. Line 3: Expected ratio from the seasonal cycle in cloud cover. Line 4: Expected ratio from the seasonal differences in albedo. Line 5: Product of ozone, cloud, and albedo influences. Line 5 is similar to line 1, indicating that the measurements can be well explained by the influence of the three factors.

Mapping Spectrometer (TOMS) total ozone data and a parameterization of the anti-correlation of ozone and UV suggested by *Booth and Madronich* [1994] with a radiation amplification factor of 2.2. With the presumption that all atmospheric parameters, except ozone, were constant throughout the year, line 2 indicates the DNA-weighted dose is a factor of 2.5 higher in fall than in spring. This large difference can be explained by the fact that total column ozone at Barrow is about 150 DU lower in fall than in spring.

Line 3 in Figure 4 shows the spring-fall DNA ratio that would be expected from the annual cycle in cloud cover if clouds were the only parameter affecting UV. Cloud cover data provided by the National Climatic Data Center shows the relationship between cloud cover and attenuation of DNA-weighted irradiance, and was parameterized according to *Thiel et al.* [1997], assuming stratocumulus clouds are prevailing. Line 3 indicates that DNA doses can be expected to be higher in spring by about a factor of 2 because of fewer clouds in the first part of the year. Thus the annual cycle in cloud cover partly cancels out the influence of the ozone cycle.

Variability in surface albedo is another important parameter affecting DNA irradiance at BRW. Albedo measurements from BRW indicate that the ground is completely covered by snow between the beginning of November and the end of May [*Dutton and Endres*, 1991]. According to data from the National Ice Center the adjoining ocean is covered by sea ice during approximately the same period, thus causing high albedo beyond the immediate vicinity of the measurement site. Comparisons of SUV-100 spectral measurements to radiative transfer model calculations show that the effective UV albedo is 0.85 during this period. This causes an increase of DNA-weighted irradiance of about 52% compared to snow-free conditions that prevail in Barrow between the beginning of July and mid-September. Finally, line 4 in Figure 4 indicates the spring-fall ratio of the DNA dose that can be expected from the albedo variability.

By multiplying the spring-fall ratios that were calculated previously for the effects of ozone, clouds, and albedo on the DNA dose, the combined influence of all three parameters was determined. The resulting product is line 5 in Figure 4. The curve is very similar to the measured spring-fall asymmetry in the DNA dose (line 1), indicating that the measurement can be well explained by the seasonal cycles of the three factors. Remaining deviations are partly due to the simple parameterizations applied. For example, nonlinear interference of albedo and cloud reflections were not taken into account. In addition not all time-series were complete for the 1991-1997 period; for example, no TOMS data exist for 1995.

## SUMMARY

High spectral resolution scanning UV spectroradiometers have been established at six sites, including SPO and BRW, and are successfully providing multi-year data sets. The database is now sufficiently large to investigate the UV climatology at all sites beyond year-to-year variability. This has been demonstrated for Barrow, where data from 1991-1997 were used to analyze the impact of ozone, cloud, and albedo variations on biologically relevant levels of DNA-weighted daily doses.

Data from the network are distributed by Biospherical Instruments Inc. via CD-ROMs and the Internet to interested researchers. Investigations based on this dataset were published or referenced by scientists from around the world in more than 100 peer-reviewed publications. The Data and Network Operation Report ordering, more detailed information on the deployed instrumentation, and an extensive list of references are available on the website (http://www.biospherical.com).

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