High Arctic UV radiation levels in the spring of 2011 caused by unprecedented chemical ozone loss

Biospherical Instruments Inc.

G. Bernhard[1], V. Fioletov[2], A. Heikkilä[3], B. Johnsen[4], T. Koskela[3], K. Lakkala[5], C. Lund Myhre[6]

[1]Biospherical Instruments Inc., San Diego, California, USA; bernhard@biospherical.com
[2]Environment Canada, Toronto, Ontario, Canada | [3]Finnish Meteorological Institute, Helsinki, Finland | [4]Norwegian Radiation Protection Authority, Østerås, Norway
[5]Finnish Meteorological Institute, Arctic Research Centre, Sodankylä, Finland | [6]Norwegian Institute for Air Research, Kjeller, Norway

NILU

Environment Canada

The "Arctic ozone hole" of 2011

Ozone concentrations in the Arctic stratosphere during March 2011 were the lowest ever recorded (Manney et al., 2011). The minimum total ozone column for March 2011, averaged over the "equivalent latitude" band 63°–90° N was 297 DU. The previous record-low, was 315 DU (Dobson Units), and was observed in 2000.

The fraction of the Arctic vortex with total ozone below 275 DU is typically near zero for March, but reached nearly 45% in March 2011. Minimum total ozone in spring 2011 was continuously below 250 DU for about 27 days. Values between 220 and 230 DU were reached for about one week in late March 2011.

The ozone loss in the spring 2011 was comparable to that observed during the annually-recurring "ozone hole" over the Antarctic. The record loss was mostly caused by chemical destruction of ozone, attributed to the existing stratospheric burden of ozone-depleting halogens and favored by an unusually prolonged cold period in the lower stratosphere in 2011, which facilitated the formation of polar stratospheric clouds (PSC),

Temperatures below the threshold temperature for PSC formation existed between December 2010 and early April 2011. Once formed, PSCs activated stratospheric chlorine, which in turn led to the destruction of ozone. Over 80% of the ozone present in January from about 18 to 20 km altitude had been chemically destroyed by late March (Manney et al., 2011).

The effect of ozone loss on UV radiation

The low levels of total ozone led to elevated UV levels throughout the Arctic and sub-Arctic. Figure 1 quantifies this increase in terms of the noontime UV Index, which is a measure of the ability of UV radiation to cause sunburn in human skin.

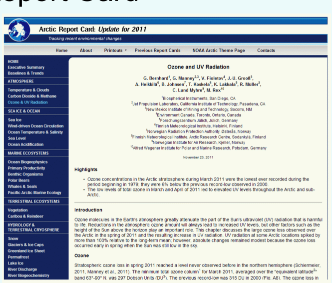
The following conclusions can be reached from Figure 1:

- Changes in the UV Index anti-correlate with changes in total ozone (compare 2011 data in third and forth plot for each site).
- Noontime UV Indices of March 2011 exceeded historical measurements for this month at all Arctic sites where ground-based UV monitoring systems are located. The maximum enhancement of the UV Index relative to the climatological mean was 122%. (See Relative UVI Anomaly plot for Andoya.)
- While these large relative changes are unprecedented, the absolute increases in UV levels were modest at all sites, for example, the maximum increase was two UV Index units and observed in Finse. (See "Absolute UVI Anomaly plots). The increases were modest because the low-ozone event occurred early in spring when the solar elevation was still small.
- Larger absolute increases of UV Indices occurred at lower latitudes during excursions of the polar vortex in April. For example, on April 22, the clear-sky UV Index over parts of Mongolia (48°N, 98°E) was 8.6 when a lobe of the vortex extended to central Asia. The long-term average for this day at this location is 5.4 with a standard deviation of 0.5, that is, the anomaly was more than six standard deviations larger than the climatological mean.

The NOAA Arctic Report Card

This poster was motivated by an essay on Ozone and UV Radiation prepared by the authors for the "2011 NOAA Arctic Report Card" (Bernhard et al., 2011), available at:

http://www.arctic.noaa.gov/reportcard/ozone_uv.html



This peer-reviewed assessment report is a timely source for clear, reliable and concise environmental information on the state of the Arctic, relative to historical time series records.

Noontime UV Index and total ozone

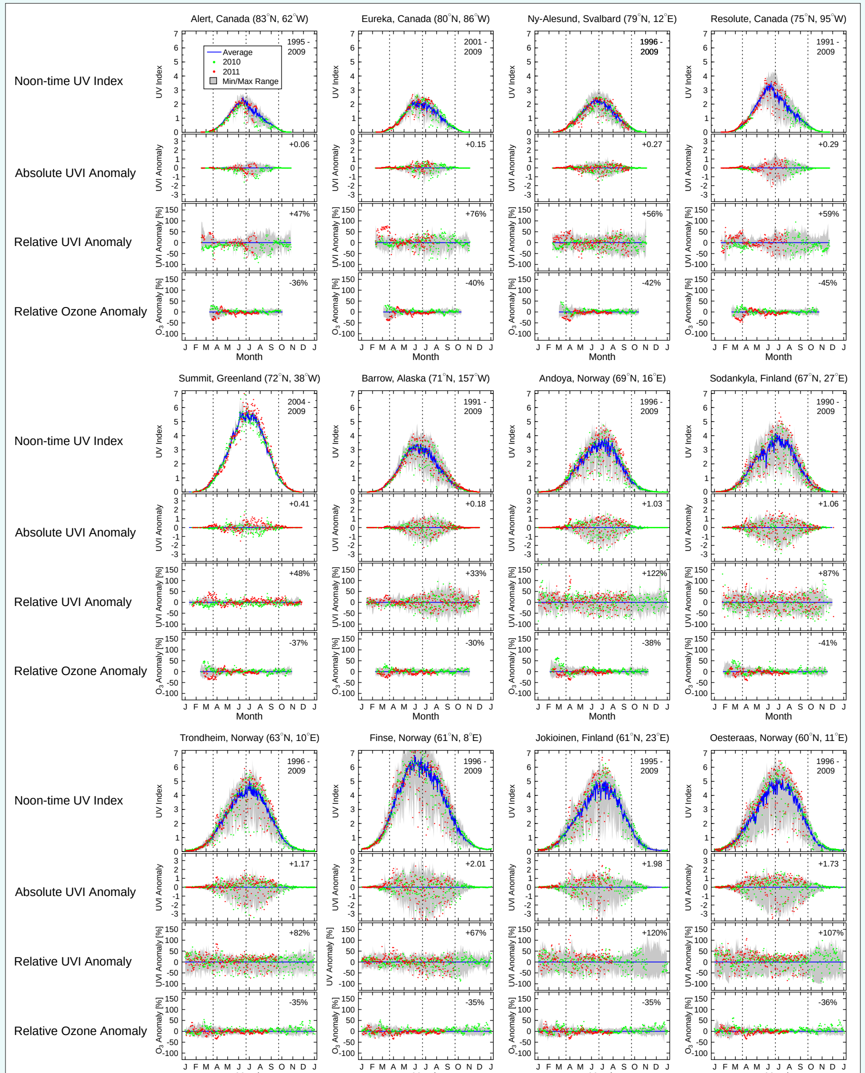


Figure 1: Seasonal variation of the noontime UV Index for twelve Arctic and sub-Arctic sites measured by ground-based radiometers.

The first plot for each site compares the climatological average (blue line) with the measurements in 2011 (red dots), the measurements in 2010 (green dots), and historical minima and maxima (shaded range). The latter were calculated from measurements of the periods indicated in the top-right corner of the panel.

The second plot shows the anomaly of the UV Index in absolute terms, calculated as difference between measurements and the average.

The third plot shows the relative UV Index anomaly calculated as the percentage departure from the climatological average.

The forth plot shows a similar anomaly analysis for total ozone derived from satellite measurements (TOMS and OMI).

Numbers in Plots 2 – 4 indicate the maximum anomalies for March and April 2011.

Cumulative UV Dose

The analysis of Figure 1 is based on instantaneous UV measurements at solar noon. This measure is useful for quantifying the risk of getting sunburned but is less relevant for plants and animals that cannot avoid the Sun. For these, cumulative UV exposures over an extended time-period is a more suitable quantity.

Figures 2 and 3 compare the erythemal ("sunburning") UV dose received during the low-ozone episode in 2011 with the dose received during the same period in previous years. For the high Arctic sites of Ny-Ålesund, Summit and Barrow (Figure 2), this period started at the end of the polar night. For the Scandinavian sites of Andøya, Sodankylä, Trondheim, Finse, and Østerås (Figure 3), the episode occurred between 24-March and 4-April 2011.

At all sites, the erythemal dose received during the 2011 low-ozone episode was either the highest or second-highest of all years. Additional statistics are provided in Table 1. For example, the 2011 dose received during the episode exceeded the climatological average by more than 2.5 standard deviations at several sites.

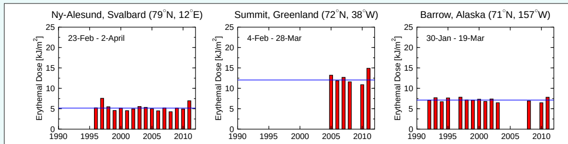
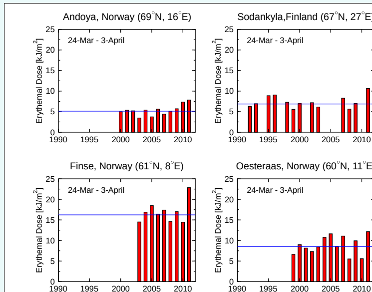


Figure 2: Erythemal UV dose for periods indicated in the top left corner of each plot as a function of year. The average dose calculated from all years except 2011 is shown as blue line.



At the time this poster was drafted, final data for the Canadian sites and Jokioinen were not available. These sites will be added when a more formal publication of this work is prepared.

Figure 3: Same as Figure 2 but for Scandinavian sites.

Table 1: Statistics of low-ozone event of 2011

Parameter	Ny-Ålesund	Summit	Barrow	Åndoya	Sondankyla	Trondheim	Finse	Østerås	Unit
Statistics of noontime UV Index									
Day of year of maximum relative increase	51	69	68	88	90	89	87	87	Day of year
Maximum relative increase	56%	48%	33%	121%	87%	82%	67%	107%	Percent
"Days too early"#	11	7	5	**29**	**23**	**27**	**27**	**27**	Days
Statistics of cumulative erythemal dose and annual dose									
Low-ozone period	23-Feb 2-April	4-Feb 28-Mar	30-Jan 19-Mar	24-Mar 3-April	24-Mar 3-April	24-Mar 3-April	24-Mar 3-April	24-Mar 3-April	
Erythemal dose for 2011 low-ozone period	6.96	14.91	7.82	7.84	10.64	11.15	22.85	12.16	kJ/m2
Climatological dose for this period	5.16	12.05	7.13	5.12	6.87	7.33	16.23	8.55	kJ/m2
Standard deviation for this period	0.76	0.92	0.45	1.04	1.06	1.09	1.52	2.05	kJ/m2
Relative dose enhancement for 2011	34.7%	23.7%	9.7%	53.1%	55.0%	52.0%	40.8%	42.3%	Percent
Relative enhancement in standard deviations	**2.35**	**3.11**	1.54	**2.61**	**3.55**	**3.49**	**4.35**	1.76	(factor)
Climatological annual dose	207.3	526.4	302.8	245.8	291.2	320.3	499.5	366.6	kJ/m2
St. dev. of annual dose	13.1	13.8	12.5	14.4	22.1	12.4	23.9	12.2	kJ/m2

Number of days between the day when the maximum relative increase occurred in 2011 and the day when the same UVI typically occurs.

References

Bernhard et al., 2011: Ozone and UV Radiation, in: NOAA Arctic Report Card: Update for 2011, edited by J.-Richter-Menge, M. O. Jeffries and, J. Overland, and J.-Richter-Menge, available at http://www.arctic.noaa.gov/reportcard/.

Manney et al., 2011: Unprecedented Arctic ozone loss in 2011, Nature, 478, 469-475.

This study was funded by the U.S. National Science Foundation, Grant ARC-0856268.