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25 Years of Spectral UV Measurements at Sodankylä

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Abstract. At Sodankylä (67°N), spectra of solar ultraviolet radiation (UVR) have been measured with a Brewer spectroradiometer since 1990. The time series is one of the longest in the European Arctic region. In this work, the time series 1990-2014 was homogenized, and the data were corrected with respect to known error sources using laboratory characterizations and theoretical approaches. Methods for cosine correction, temperature correction and determination of long-term changes in spectral responsivity were applied. Bad measurements were identified by using various quality assurance tools including comparisons with reconstructed UV dose rates, synchronous broadband UV dose rates, global radiation and clear sky model calculations. We calculated daily maximum UV indices from the spectral time series. The daily maxima reached on average a value of 5 in midsummer, whereas the maximum UV index value of 6 was measured only twice: in 2011 and in 2013. We calculated the relative spectral changes in measured UV irradiances. An anti-correlation with total ozone was found in April and June, but no statistically significant long-term changes were found. The effect of snow, enhancing the measured UVR due to high albedo, was important during late spring. Short-term variations were mostly due to changes in cloudiness, which was the dominant factor during summertime.

INTRODUCTION

In this work we studied the 25 year long time series (1990–2014) of spectral UV measurements measured at the Finnish Meteorological Institute – Arctic Research Centre (FMI–ARC), fmiarc.fmi.fi. The spectral UV irradiance was measured with a Brewer spectroradiometer, type Mark II, since 1990 [1,2]. The time series is one of the longest measured in the Arctic, and the time period covers the events of high springtime stratospheric ozone loss in the 90's and the beginning of this century [3,4]. The key question was, could we find significant spectral changes in the measured UV irradiances. For this purpose, the time series had to be homogenized and the data had to undergo proper quality assurance (QA) procedures [5,6].

MATERIALS AND METHODS

Brewer measurements at Sodankylä

The FMI-ARC (67°N, 26°E) is located 7 km South from the Sodankylä village on the banks of the river Kitinen surrounded by pine forest and peatland. From the point of view of its stratosphere, Sodankylä can be classified as an Arctic site, often lying beneath the middle or the edge of the stratospheric polar vortex in the area of springtime polar stratospheric ozone loss [7]. The smallest solar zenith angle (SZA) is 44° at midsummer, and the sun is below the horizon between December and January. There is snow cover from September/October to April/May.

The MK II Brewer spectroradiometer (Brewer) no. 37 manufactured by SCI-TEC Instruments Inc, Canada, was set up on the roof of the sounding station of the FMI-ARC in 1988 to measure total ozone. First spectral UVR measurements that could be homogenized are from 1990. Since then, regular lamp calibrations were performed, first with 50 W lamps, and since 1998 with 1 kW lamps. The primary standard was traceable to The Metrology Research Institute, MIKES-Aalto, which is the Finnish National Standards Laboratory for optical quantities. Using the lamp

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calibrations the spectral response of the Brewer could be determined and the response time series homogenized. The relative response time series at 311 nm is shown in Figure 1. The sudden severe drop in 1993 in the responsivity is due to the accidental overheating of a heating element inside the instrument box. After this accident, the responsivity rose to almost it's previous level after which ageing has occured, showing a downward drift of a couple of percent per year.

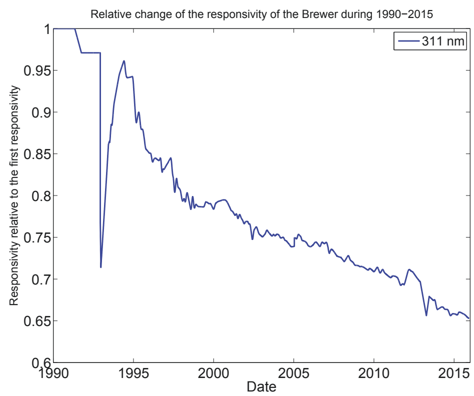


FIGURE 1. Response time series relative to the first measurement at 311 nm during 1990-2015.

The Brewer no. 37 had a Teflon diffuser, a single grating monochromator and a photomultiplier tube, and measured spectral irradiance in the wavelength range from 290 to 325 nm with steps of 0.5 nm. The Brewer measured on average every half an hour using a predefined schedule. The scanning time of the whole spectral range was around 4 minutes. The full width at half maximum of the slit function was 0.56 nm.

The data processing of the Brewer UVR measurements included corrections of errors due to dark current, stray light, dead time, angular dependence, temperature dependence and wavelength misalignment [2,6]. After these routine corrections, the quality of the data were assured using comparisons with reconstructed UV dose rates, synchronous broadband UV dose rates and global radiation, and clear sky model calculations [6]. Bad measurements were excluded from the data. The Brewer measurements were also compared 5 times during 2002-2014 with the portable reference spectroradiometer QASUME (Quality Assurance of Spectral Ultraviolet Measurements in Europe,[8]). The differences were within 6% for wavelengths longer than 305 nm (http://www.pmodwrc.ch/euvc/euvc.php?topic=qasume audit#). The final spectral UV time series 1990-2014 was submitted to the European UV data base EUVDB [9], uv.fmi.fi/uvdb.

Data analysis

As an example of the final UVR time series, the daily maximum UV indices measured during 1990–2015 are plotted in Figure 2. From the daily maximum UV index time series, the average, minimum and maximum were calculated for each day of the year.

To study the spectral changes, we selected data measured at SZAs between 63° and 65°, which included data from mid-March until mid-September. This allowed the results to be comparable with [1]. A linear regression line was fitted to the monthly mean irradiances of each month between April and August. This was done to each wavelength between 300 and 325 nm at steps of 1 nm. The Student t-test was used to test the significance of the observed change. For our dataset, using the 95% confidence level, the Student t-test t value should be over 2.06 to obtain statistically significant changes.

RESULTS AND DISCUSSION

The average, maximum and minimum values of the daily maximum UV indices during 1990-2015 are shown in Figure 3. At Sodankylä, the maximum measured UV index value of 6 was measured twice: 30 June 2011 and 29 June 2013. The snow cover enhanced the UVR during springtime, which can be seen when looking at the shape of the line of

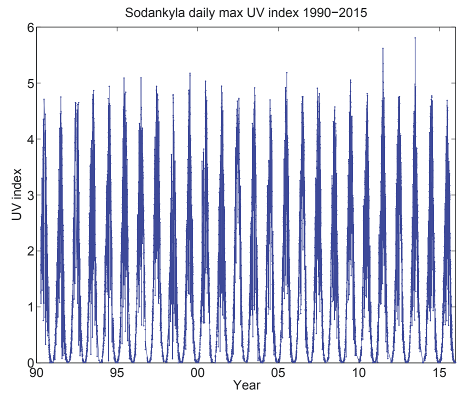


FIGURE 2. The daily maximum UV index time series measured with the Brewer spectrophotometer during 1990-2015 at Sodankylä, Finland.

the maximum values. Clear sky conditions were also more frequent during springtime than during summertime, when changing cloud cover was the dominant factor of short-term UV changes.

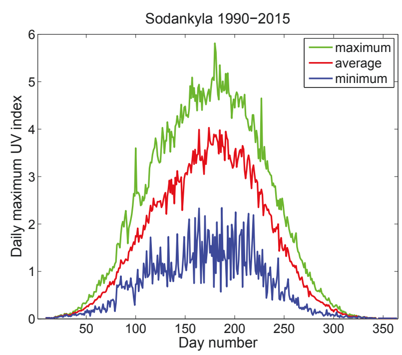
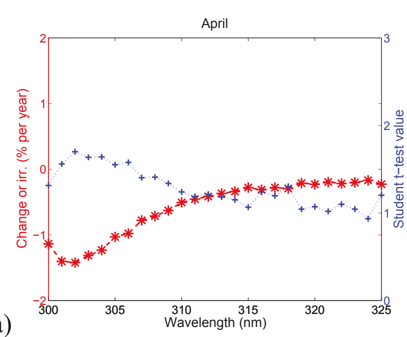


FIGURE 3. The average, maximum and minimum values of the daily maximum UV index during 1990-2015.

The relative spectral changes (1990–2014) in UV irradiances are shown in Figure 4. A wavelength dependence can be seen in the observed change in April and June, where the short wavelengths show a more negative change than the longer wavelengths. This could suggest a positive change in the corresponding total ozone time series. However, no observed changes are statistically significant. A linear fit to the monthly means is not the best way to analyze these kind of time series. The influence of years with strong springtime stratospheric ozone loss (e.g. 1993, 1996, 1997 in April, see Figure 4f) is obvious, and it could be better to study the time series piecewise.



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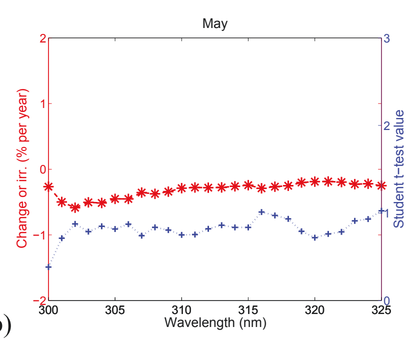

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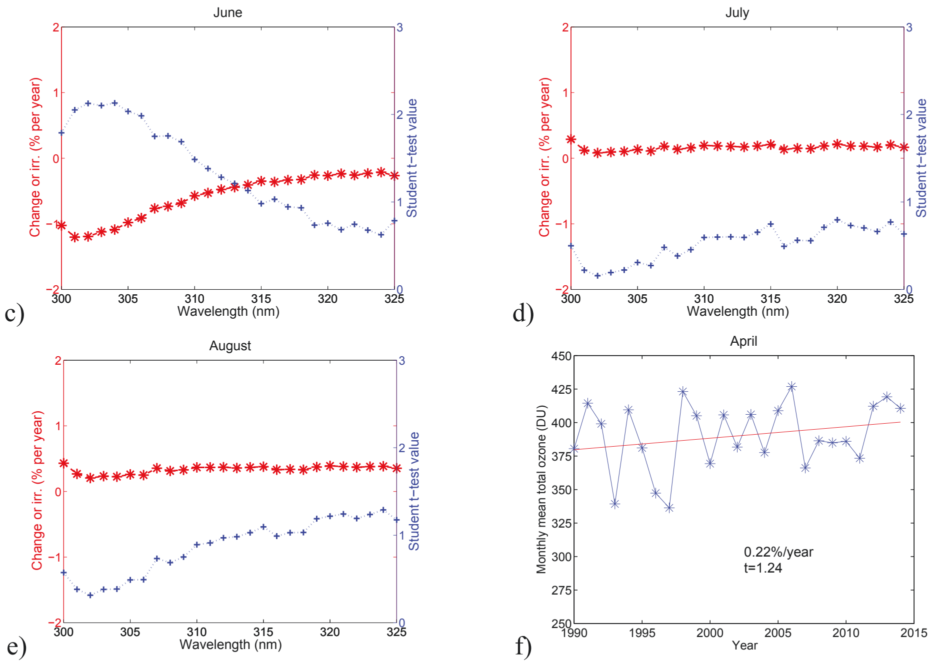

FIGURE 4. Relative spectral changes (% per year) in UV irradiances calculated from a linear regression line fitted to monthly means in April (a), May (b), June (c), July (d) and August (e) during 1990–2014. Total ozone monthly means (f), linear fitting and the relative change (1990–2014) is also shown for April.

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