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Variability of Daily UV Index in Jokioinen, Finland, in 1995-2015

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Abstract. UV Index is a measure for UV radiation harmful for the human skin, developed and used to promote the sun awareness and protection of people. Monitoring programs conducted around the world have produced a number of long-term time series of UV irradiance. One of the longest time series of solar spectral UV irradiance in Europe has been obtained from the continuous measurements of Brewer #107 spectrophotometer in Jokioinen (lat. 60°44'N, lon. 23°30'E), Finland, over the years 1995-2015. We have used descriptive statistics and estimates of cumulative distribution functions, quantiles and probability density functions in the analysis of the time series of daily UV Index maxima. Seasonal differences in the estimated distributions and in the trends of the estimated quantiles are found.

INTRODUCTION

UV index is a simple measure for UV radiation causing erythema (reddening) of the human skin. Since its introduction in 1992, it has been widely used to promote the sun awareness and protection of people. The index is calculated from the instantaneous dose rate of erythemally weighted solar UV irradiance. For the UV Index forecasts, it is derived from the dose rate computed by a radiative transfer model. The realized UV Index may be derived from either ground-based or space-borne measurements of solar UV irradiance. Indeed, the realized UV Index is often computed as a reference to the forecasted UV Index.

Monitoring programs conducted around the world have produced a number of long-term time series of solar UV irradiance. One of the longest time series of solar spectral UV irradiance in Europe has been obtained from the continuous measurements of Brewer#107 spectroradiometer in Jokioinen (lat. 60°44'N, lon. 23°30'E), Finland, over the years 1995-2015. Computation of UV Index has been realized as part of the processing of these data. The data set provides an opportunity to explore the temporal development and variability of solar UV radiation harmful to the humans over two decades at a site close to the population centre of Finland.

MATERIALS AND METHODS

Measurements of solar spectral UV irradiance were launched in Jokioinen (60.82°N, 23.50°E, 107 asl), Finland, in April 1995. The site is rural and mainly surrounded by fields and coniferous forests. The ground is typically snow covered over the winter months. The ambient temperature ranges from +30°C in summer to as low as -30°C in winter. The amount of atmospheric aerosols is low, and the cloudiness is fairly variable throughout the year.

The instrument used for the measurements is Brewer MkIII spectrophotometer #107. The instrument employs a double monochromator with a sun tracker. The measurand is global horizontal spectral UV irradiance over the UV wavelengths 286.5–365 nm with a step of 0.5 nm. The FWHM of the slit function of the monochromator is 0.59 nm. Rigorous standard operation and QC/QA procedures are routinely applied [1-2]. The data flow is organized to produce data sets of three different levels: Level 0, Level 1 and Level 2, as a result of gathering of raw data, near-real-time processing, and post-processing, respectively [3]. A multitude of products are derived for both Level 1 and Level 2 data, including the UV Index.

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The UV Index is calculated using a three-step procedure. First, the measured solar UV irradiance spectrum in units W m^{-2} nm^{-1} is multiplied by the dimensionless action spectrum for erythema [4]. Second, the weighted spectrum is integrated over the wavelengths of UV radiation, to obtain the erythemally weighted dose rate in units W m^{-2}. Finally, the erythemally weighted dose rate is multiplied by factor 40, to yield the UVI Index. The index is a dimensionless number usually between 0-20 that is more easily comprehended than the instantaneous dose rate. In this study, we confine the analysis to the daily maxima of UV Index.

The daily maxima of UV Index (hereinafter referred to as UVI) were examined for the annual cycle and for the monthly frequency distributions using descriptive statistics. Next, the data were analyzed using quantiles of 0.05, 0.25, 0.5, 0.75 and 0.95. Both the annual cycles and the monthly time series of the quantiles were investigated. The CDFs (cumulative distribution functions) of UVI maxima, F(UVI), were estimated using linear interpolation between observations ranked in increasing order, and from the empirical CDF formula

$$\hat{F}(UVI_i) = \frac{i}{1+n}, \tag{1}$$

where UVI_i is the ith lowest observation and n is the number of observations. Finally, kernel density estimation employing the Epanechnikov kernel was used to derive density functions for UVI.

RESULTS AND DISCUSSION

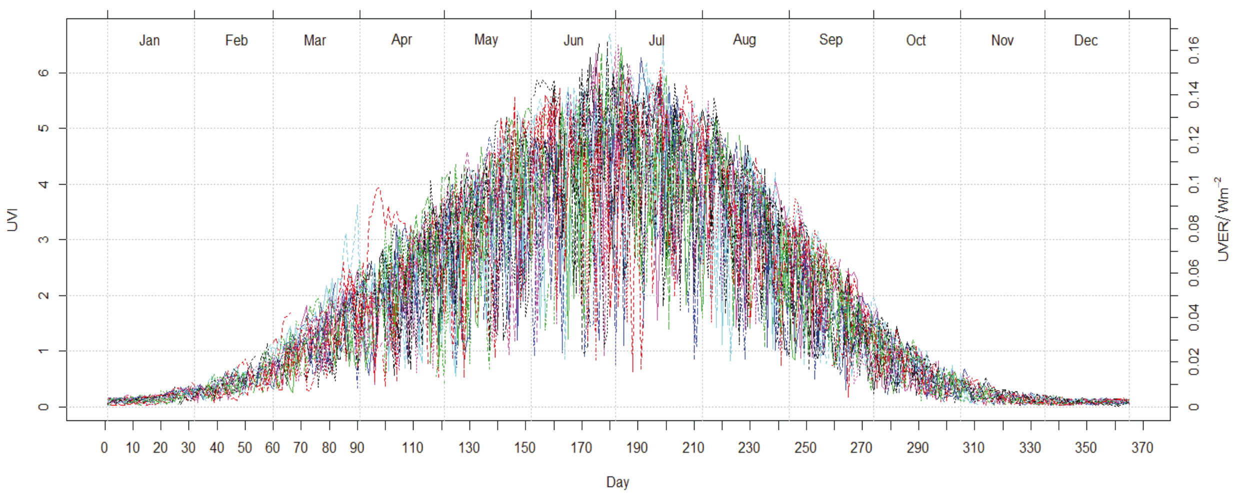

FIGURE 1. Daily UV index maxima measured by Brewer #107 spectrophotometer at Jokioinen, Finland, in 1995-2015.

Figure 1 shows a plot of all the daily UV Index maxima measured at Jokioinen over the years 1995-2015, each line representing a particular year. The annual cycle is clearly distinguishable. The highest values are obtained in June-July. During the winter months, the values are at their lowest. The highest UV Index ever is 6.7, measured on Jun 29, 2011. On average, the value 6 meaning high risk of harm from unprotected sun exposure is reached on eight days per year. Inter-annual variability is large, however. In 2003, the UVI value of 6 was reached on one day only, whereas in 2011, the number of days with UVI reaching the value of 6 was 19. The two distinct anomalies peaking in springtime have occurred in 1996 and 2011. In both cases, the anomaly has been caused by the combination of a persistent snow cover with high albedo, an exceptionally low amount of atmospheric total column ozone, and at least partially clear sky conditions.

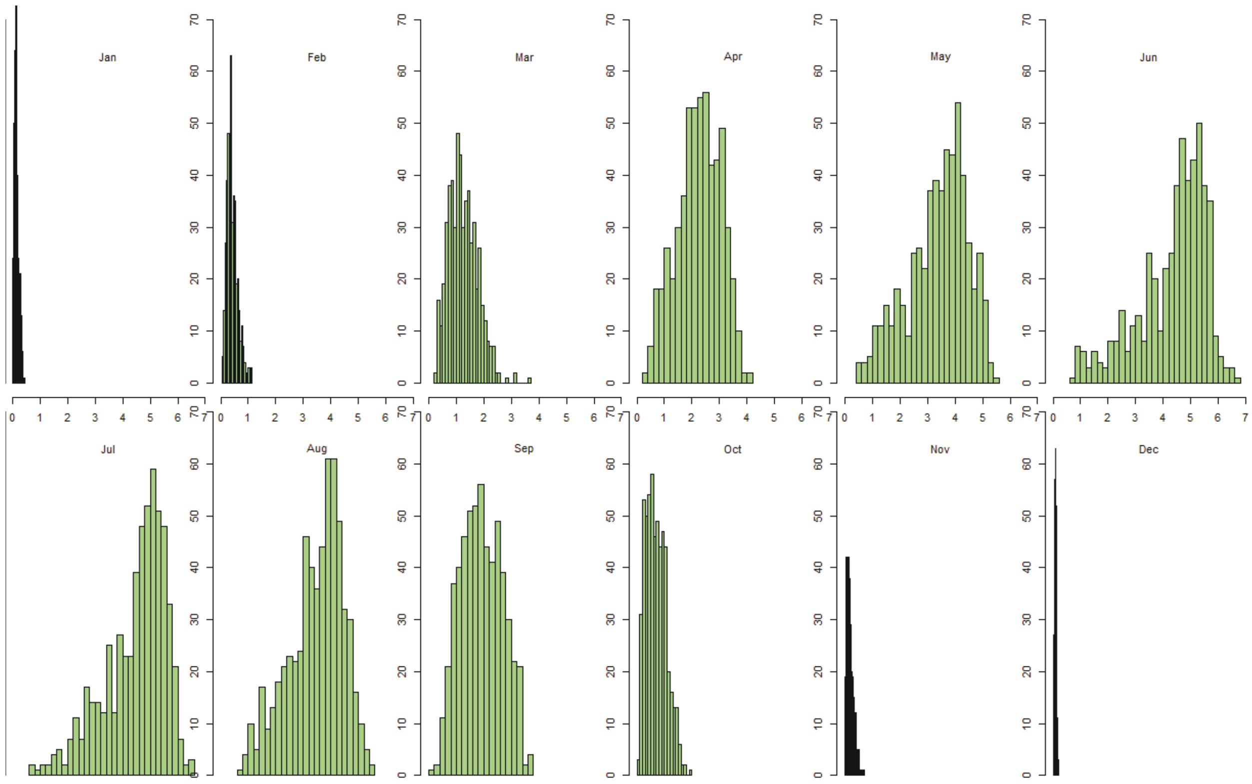

FIGURE 2. Monthly frequency distributions of the daily maximum UV index measured by the Brewer #107 spectrophotometer at Jokioinen, Finland, in 1995-2015. Horizontal axes: daily UVI maximum, vertical axes: frequency.

Figure 2 describes the monthly frequency distributions of daily UV Index maxima. The natural annual cycle of solar UV radiation is obvious, the summer months exhibiting the widest range of values. The distributions are left-skewed during summer and right-skewed during winter and they extend over limited range. In this way the distributions resemble the beta distribution. The direction of the skewness depends on the parameters of the beta distribution. Cautiousness is needed in attempts to apply statistical methods requiring normally distributed data.

Figure 3 provides quantiles of UVI corresponding to estimated cumulative probability of UVI. To facilitate recognition of regular patterns, individually fitted linear trends were added to smooth out random variations in UVI quantiles. The estimation was based on linear interpolation between observations UVI_i and UVI_{i+1}, where the UVI_i were ranked in increasing order. At the observations $i=1,2,...,n$, $F(UVI_i)=P(UVI \leq UVI_i)$ was estimated by the formula (1), which according to the theory of order statistics is equal to $E(F(UVI_i))$ under ideal conditions, i.e. if UVI_i are independent and identically distributed (i.i.d.). In our case, however, the conditions are not ideal. For example, it is obvious that the data within the month is autocorrelated because the observations are made in consecutive days and weather patterns may last over several days or longer. The trends fitted into the estimated quantiles exhibit month-to-month variation, with some seasonal dependence. The median, for instance, seems to increase in time in May-Aug, but to decrease in Mar-Apr and Sep. Figure 3 also displays a complementary way to illustrate the distributions of UVI data as the probability densities (in red) obtained by kernel estimation using the Epanechnikov kernel.

CONCLUSIONS

The twenty-year time series of daily UV Index maxima derived from the measurements of Brewer #107 MkIII spectrophotometer in Jokioinen, Finland, in 1995-2015, were analyzed for their distributions using estimations of cumulative probability, the corresponding quantiles, and probability density function. Large inter-annual variability and notable differences in the monthly distributions were found. The cumulative probabilities and the corresponding quantiles may indicate some seasonal dependence. However, upon application of statistical methods, it should be noted that the observations are autocorrelated and the distributions are far from normal..

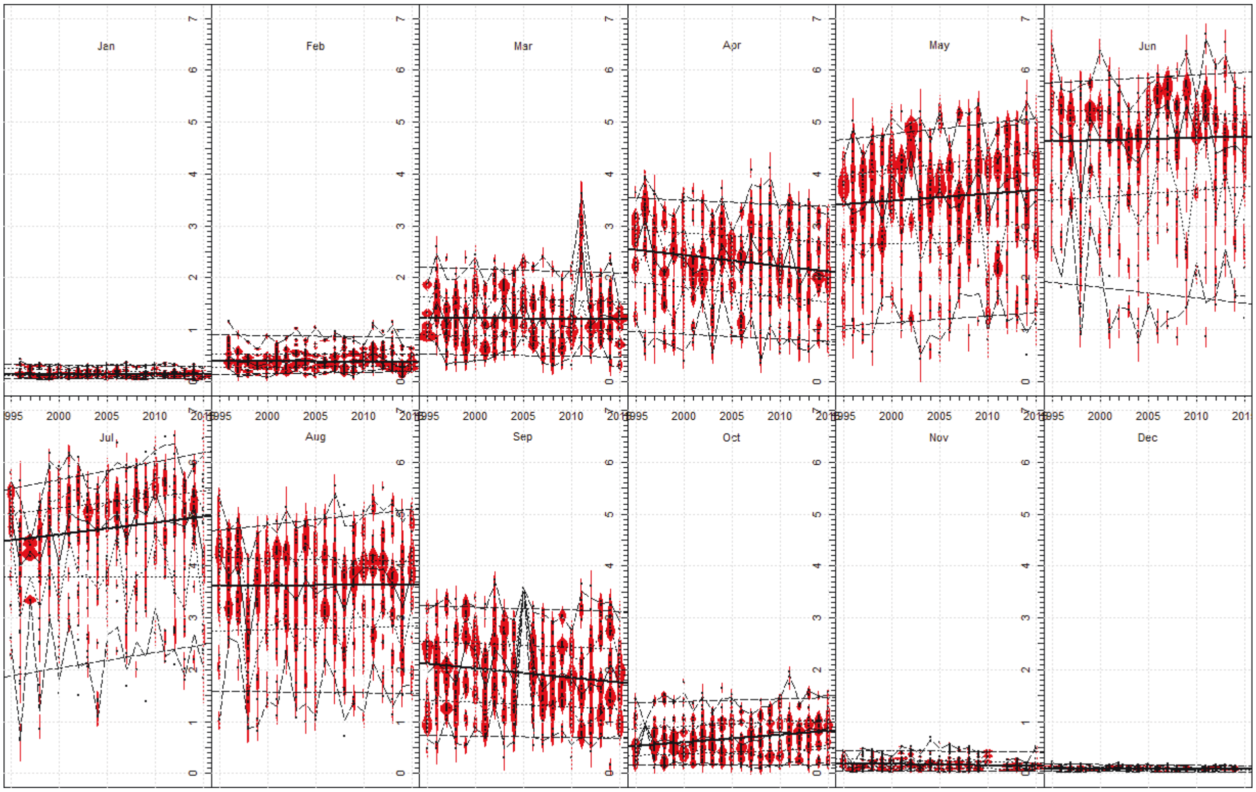

FIGURE 3. Time series of the monthly distributions of the daily UV index maxima measured by the Brewer #107 spectrophotometer at Jokioinen in 1995-2015 (observed daily UV index maxima as black dots); estimated quantiles with the regression lines (solid line: median, dashed lines: quantiles for 0.25/0.75 and 0.05/0.95), and estimated densities in red.

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