Abstract
Solar erythemal UV radiation (UV\textsubscript{ER}) is highly relevant for plants, animals, and human health. Despite this fact, long-term records of UV\textsubscript{ER} are scarce and although a recovery of the stratospheric ozone layer is anticipated by the middle of the 21st century, there is a strong interest in the temporal variation of UV\textsubscript{ER} time series, especially in urban areas. We combined ground-based measurements with modeled ozone data sets to reconstruct time series of monthly totals of UV\textsubscript{ER} for the city of Potsdam, Germany. Artificial Neural Networks were trained with measured UV\textsubscript{ER}, sunshine duration, measured and modeled total column ozone, as well as the minimum solar zenith angle. Thus it is possible to reconstruct monthly totals of UV\textsubscript{ER} for the period from 1901 to 1999. Additionally, analyses of long-term variations of the reconstructed, new UV\textsubscript{ER} data set are presented.

Key words: artificial neural network (ANN), erythemal UV radiation, ozone, Potsdam, time series re-construction, trend analysis

1. INTRODUCTION
Erythemal UV radiation (UV\textsubscript{ER}) is the weighted integral over spectral UV irradiance from 280 nm to 400 nm with the erythemal action spectrum (McKinley & Diffey 1987) as a weighting function. UV\textsubscript{ER} exerts several impacts on plants, animals as well as human health, albeit long-term records of solar UV radiation are rare. Because most of the existing measured UV time series are relatively short, it is not possible to analyze long-term changes in the UV radiation caused by observed variations of e.g. total column ozone (O3) or aerosol optical depth. Although a recovery of the stratospheric ozone layer is anticipated for the middle of the 21st century, there is a strong interest in the temporal variation of erythemal time series. Therefore, short ground-based O3 and UV\textsubscript{ER} measurements recorded at the Meteorological Observatory Potsdam, Germany (52° 22'N, 13° 5'E, 107 m a.s.l.) were combined with 100-year long time series of column O3 simulated with CCM SOCOL and corrected for seasonal deviations to measured data to reconstruct long time series of monthly totals UV\textsubscript{ER} (Fischer et al. 2008). Different Artificial Neural Networks (ANN) were trained with recent measurements of solar UV\textsubscript{ER}, sunshine duration, day of the year (DOY), measured and modeled O3 as well as the minimum solar zenith angle. Other parameters, which have been successfully used in other studies, e.g. global radiation or aerosol optical depth, were not used because these measurements were not available dating back to 1901. Our methodology has been successfully applied in projects like the COST 726 Action (“Long-term changes and climatology of UV radiation over Europe”) and the SCOUT O3 project (“Stratospheric-Climate Links with Emphasis on the Upper Troposphere and Lower Stratosphere”). Using long-term sunshine duration, modeled O3 data, the solar zenith angle and the DOY, we reconstructed a time series of monthly totals of UV\textsubscript{ER} for the period from 1/1901 – 12/1999. Finally trend analysis of the reconstructed UV\textsubscript{ER} data sets were done.

2. DATA AND METHODS
Data sets used in this study are daily values of sunshine duration (1901 to 1999), measured (1/1995 to 12/1999) and modeled (1901 to 1999) O3 data, calculated minimum solar zenith angles as well as daily totals of UV\textsubscript{ER} (1995 to 1999). The 100-year time series of measured sunshine duration shows almost no missing values. Only three complete months in the whole period are missing. These gaps were replaced by 30-year climatological means, centered on each missing value.

UV irradiance was measured with Brewer spectroradiometers (#030 MKII, and #118 MKIII) up to two times per hour. The cosine error of the Brewer instruments was accounted for by a correction that is applied to the measured Brewer spectra (Feister et al. 1997, Feister et al. 2008).

O3 measurements for the Potsdam site are based on direct sun and zenith sky measurements with Dobson spectrophotometers #64 and #71. Since O3 has a major influence on the UV\textsubscript{ER} radiation, using the long-term modeled time-series of O3 for Potsdam as a predictor in the ANN model was expected to improve modeled UV\textsubscript{ER}. 1349 days of matching data in the time series remained for training of the ANN model, whereas the minimum solar zenith angle, DOY, sunshine duration and additionally O3 were used as predictors. With the neural network approach the empirical relationship among sunshine duration and UV\textsubscript{ER} is used to derive the daily doses of UV\textsubscript{ER} for past time-spans.
Neural networks have been applied successfully to various studies for estimating solar irradiation (Chevallier et al. 1998, Reddy & Ranjan 2003). The most important characteristic of biological and artificial neural networks is their capability to learn from existing data sets. The neuronal network technology thereby imitates the human brain’s problem solving capability: knowledge gained from past or previous experience is applied to new problems by building a system of "neurons" that makes new decisions, classifications, or forecasts. ANNs learn a relationship between input and output data without knowing the exact physical interrelationship (Lopez et al. 1998).

3. RESULTS

3.1 COMPARISON OF MODELED AND MEASURED OZONE DATA

Before the modeled O3 data could be used as an input parameter for the ANN model to reconstruct monthly totals of UVER, the differences between the measured O3 at Potsdam and the corresponding model values have to be assessed. In Figure 1 the time series of monthly mean values of O3 as well as differences between modeled data corrected for a seasonal deviation from measurements and measured data are shown. The differences are in an acceptable range. The absolute and relative root-mean-square (RMS) error is used to evaluate the differences between measured and modeled data. The RMSE value for daily data is 46.1 (RMSR = 14.1%) and for monthly data 27.3 (RMSR = 8.3%), respectively. The monthly differences of measured and modeled O3 data show slightly higher values in winter than in summer. The model in general overestimates the yearly means of ozone concentration by less than 3%.

3.2 PREPARING THE TEST, TRAINING AND VALIDATION DATA SETS

The complete valid data set was split into four data sets for training (~60%) testing and validation (each ~12%). Additionally, the first five days of each month were removed from the original data set to get a second independent test sample for model evaluation (~16%). In order to see whether there is a significant gain of information using the modeled O3 data set, three different neuronal network topologies with varying predictors were used. The first network (A) uses the five standard predictors sunshine duration, minimal solar zenith angle, the day of the year, the month of the year and the measured O3 data to predict daily values of UV ER. The capability to predict UV ER values is used as a reference for the next two models. In the second network (B), the modeled O3 values were used instead of the measured ones. To estimate the absolute influence of O3 as a predictor O3 is omitted in the last network (C).

3.3 PERFORMANCE OF THE DIFFERENT MODELS

Figures 2 to 4 show the correlations between modeled and measured daily doses of UV ER for the period between 1/1995 and 12/1999. A clear relationship between the modeled and measured UV ER values can be observed, with an increasing amount of scatter, if O3 is not used as a predictor. A clear advantage of our approach is its independence from meteorological seasons; so one model is sufficient (Lindfors & Vuilleumier 2005). The seasonal variation of sunshine duration and UV ER is directly considered in the model setup. This makes the DOY and the solar zenith angle important predictors. The ANN model using the measured O3 (Figure 2) shows the best results with a correlation coefficient of 0.987 and a relative RMS of 10.8% in daily erythemal irradiation. The RMS is reduced to 3.5% for monthly data. Only a slight decrease to 0.96 of the correlations coefficient occurs using modeled O3 data in model B (Figure 3). The performance of model B is nearly the same in all seasons with slightly lower correlations during summer. In general, this model underestimates the yearly totals of UV ER radiation by 3.0%. More than 71% of the modeled monthly mean values are found within ± 10% of the measured data, and 93% lay within ± 20%. This is comparable with the results of other studies, e.g. Lindfors et al. (2003) for Sodankylä. Feister et al. (2008) or Junk et al. (2007) show better results, but in these studies more complex models with additional predictors were used. However, such additional input parameters are available at only few sites for such long time spans. Model C without considering O3 yields the highest RMS values, 22.9% for daily data and 19.0% for monthly values. Also the correlation coefficient decreases to 0.948 (Figure 4). These results highlight the strong dependence of daily UV ER doses on O3.
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3.4 UVER TIME SERIES RECONSTRUCTION

The ANN model predicts daily values of UVER, but their random error is rather large. Therefore our statistical analyses concentrated on monthly values and annual totals. For the reconstruction of monthly and yearly totals of UVER radiation, long input time series without missing values are essential. Gaps of only one day in the time series were filled by linear interpolation. The three missing months in the sunshine duration data set (August 1998 and 1999 as well as September 1998) were filled with long-term monthly means of the respective month. The ANN outputs are daily totals of the UVER radiation, which were used to calculate monthly and yearly totals. Figure 5 shows the estimated UVER annual totals as well as the anomalies for the period between 1901 and 1999 (mean value 4.94E+05). The annual totals vary considerably since 1901. Long-term variations are better captured by the 5-year running mean (thick black line in Figure 5). A strong increase in the annual totals of UVER from the beginning of the reconstructed time series up to the mid 1950s is followed by a less pronounced decrease between 1955 and 1990.

3.5 LINEAR TREND ANALYSES

Linear trends should be interpreted with caution, because they are mostly not capable to describe true changes of a time series, but still, they are an effective statistical method to describe past changes. Therefore trend analyses of 30-year time slices were calculated and their statistical significance was tested with the Mann-Kendall trend test (Figure 6). A period dominated by highly significant positive trends between 1901/1930 and 1924/1953 is followed by an episode with no significant trends. Between 1931/1962 and 1959/1988 smaller negative trend values can be observed. From 1965/1994 again positive trends occur (not significant). An additional trend analysis of the mean seasonal values (not shown here) indicates similar trend patterns throughout all seasons. Strong UVER increases in June to August substantially contribute to the long period with positive trend values in the first half of the 19th century, while the period with negative trend values between 1931/1962 and 1959/1988 is mostly influenced by the trend values of September, October and November. Highly significant positive trend values for time spans starting at 1964/1993 until the end of the reconstructed time series can only be found in the winter months. The overall patterns of the trend values, as well as their level of significance, show plausible distributions without extreme values in all seasons.
4. DISCUSSION AND CONCLUSION

The main objective of this study was to include the long-term O3 information in the reconstruction method to derive trends and variations in the erythemal time series. This is at the expense of the quality of the reconstruction model. Comparisons with similar studies are difficult as either different time spans or predictors are used which strongly limits the insight of such comparisons. Our results for Potsdam agree well with those presented by Lindfors & Vuilleumier (2005), who showed low values of UVER in the late 1930s, followed by an increase up to the middle of the 1940s and a steady decrease from the early 1960 up to the late 1970s. Feister et al. (2002) also detected a slight decline for Potsdam in the late 1970s using a different reconstruction method. The decline, identified from Chubarova & Nezval (2000), for UVER radiation in the summer months for Moscow for the period of 1969 to 1997 also confirms our results. A strong benefit of the ANN-approach is the fact that it can be easily adapted to different geographical locations as has been successfully tested in the framework of the COST 726 Action.

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References:


