Measured and modelled UV radiation in Norway

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Abstract: Since mid 90s, erythemal UltraViolet (UV) - radiation has been measured at 9 Norwegian stations (58 to 79ºN). As measured UV data only exist for the last decade, changes in UV climatology can only be studied by means of modelled data. One of the UV stations, Bergen, also has high quality total solar irradiance data for the last decades, and was thus selected as one of four European sites testing UV reconstruction models in the EU project COST726. The project initiated three recent Master theses, including reconstruction of UV data for different parts of Norway.

Keywords: UV radiation, observed, modelled, UV climatology, biological effects

1 Introduction

During the last decades, solar irradiance has been measured in Bergen (60.40ºN, 5.39ºE), Norway by the Geophysical Institute, University of Bergen. Hourly sunshine duration data exists from 1952 on, while hourly global and diffuse irradiance are available from 1965. In addition, Norwegian Radiation Protection Authority (NRPA) started measuring erythemal UV-radiation in 1996, and Bergen is one of 9 Norwegian stations between latitudes 58 to 79ºN, measuring GUV (Ground UltraViolet radiation; http://www.nrpa.no/uvnett). Besides, as a pilot project, both total solar irradiance and the UV-part of it have been measured since October 2007 over ocean at EKOFISK.

Because of the long time series of high quality radiation data, Bergen is selected, together with Potsdam, Davos and Thessaloniki, as test stations for UV reconstruction models in the EU project COST726: "Long term changes and climatology of UV radiation over Europe". Participation in COST726 also initiated three recent Master theses on reconstruction of UV data and validation (Sætre, 2006; Medhaug, 2007; Sjølingstad, 2007).

2 Measured and modelled UV radiation

2.1 On UV radiation

UV radiation is divided into three separate spectral regions: UVC (100 – 280 nm), which is absorbed in high atmospheric layers, and UVB (280 – 315 nm) and UVA (315 – 400 nm), which both reach the surface of the earth. Important parameters affecting UV radiation at the ground are:

- solar elevation
- total atmospheric ozone amount
- cloud amount and optical thickness
- surface albedo
- atmospheric turbidity
- air pressure.

When biological effects of UV-radiation on living organisms are to be studied, spectral irradiances have to be multiplied by an action spectrum representative for the sensitivity of the living organisms to UV radiation.

2.2 Measurements

The GUV-instruments in the Norwegian network (http://www.nrpa.no/uvnett) measure irradiance within 5 wavelengths (305, 313, 320, 340, and 380 nm) with a bandwith of 10 nm. From these measurements integrated values can be made. The effect on the human skin (erythemally weighted irradiance), is obtained by multiplying the spectral values with the action spectrum for erythema (sunburn) in the skin.

2.3 Models

The model STAR (System for Transfer of Atmospheric Radiation; Reuder and Koepke, 2005) was used for reconstruction of UV radiation in Norway, and it uses the input data listed in Chapter 2.1. For clear sky, STARsci was used (Reuder and Koepke, 2005), while for overall cloudiness, STARneuro was used. STARneuro utilizes neural network techniques, and it is trained on data from Garmisch-Partenkirchen. Additionally, the model of Lindfors (Lindfors et al., 2007) is used for comparison. Cloud modifications in this model are based on calculations by the radiative transfer model libRadtran (Mayer and Kylling, 2005), and the model is therefore not trained on measurements.

3 Results

3.1 Observed vs modelled UV radiation

In the work of Sætre (2006), hourly erythemal UV data were reconstructed by use of the STAR model. One aim was to investigate if the model was suitable for use in Bergen.

To both STAR model versions, actual solar elevation, total ozone amount and air pressure were used as input, while an average fixed aerosol optical depth (AOD) and ground albedo was chosen. For STARneuro, cloud information and global irradiance were used as additional input. As Bergen is surrounded by mountains, cases with low sun (< 10°) are therefore omitted in the comparison, and as albedo 0.03 was chosen, cases with snow are also excluded.

For clear sky cases, the ratios between measured and modelled UV had a small variation with solar elevation, but a more distinct seasonal variation (Table 1). The main reason for this distinct variation is the seasonal variation in AOD (higher values in summer than in winter), while a fixed value (0.20) for the whole year is used as input to the model.

Table 1 Ratio (R) between modelled and measured clear sky erythemal UV in Bergen (Sætre, 2006)

Season	**Winter**	**Spring**	**Summer**	**Autumn**
R	**0.97**	**1.03**	**1.12**	**1.06**

Table 2 Ratio (R) between modelled and measured erythemal UV for different cloud amounts (N; octas) in Bergen (Sætre, 2006).

N	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
R	**1.06**	**1.06**	**1.09**	**1.11**	**1.16**	**1.19**	**1.23**	**1.27**	**1.35**

According to Table 2, the small overall overestimation found at clear sky increased with increasing cloud amount. This overestimation is confirmed by Koepke et al (2007), where modelled UV values from a total of 16 models were tested against the 4 selected test stations in COST726. If absolute erythemal UV is to be estimated for Bergen, the STAR model can be used by taking into consideration correction factors given in Tables 1 and 2. When trends in

UV radiation are to be studied, the STAR model can be used if there are no trends in cloud properties (cloud amount, cloud optical thickness).

Medhaug (2007) compared modelled (STAR) and measured UV at Kjevik, Oslo, Bergen and Tromsø. For clear sky, a slight overestimation of 1–7% was found for all stations. At overcast a 10-20% overestimation was found for all stations but Tromsø, giving an overall overestimation of 11-16% for the southern stations and no deviation at Tromsø.

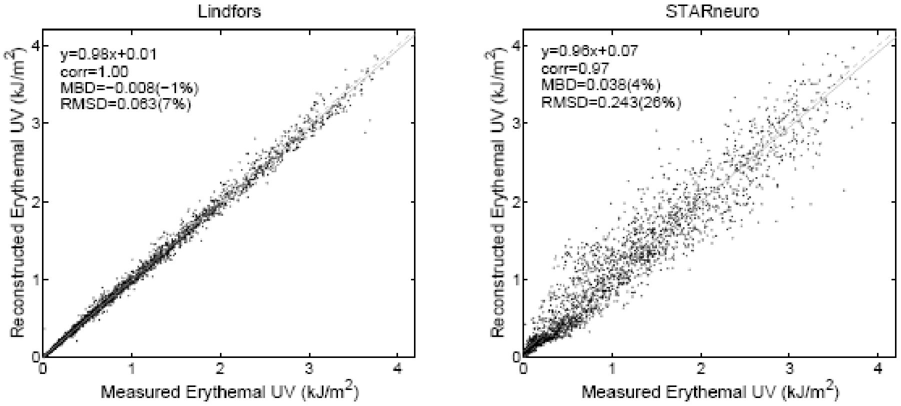

Figure 1 Reconstructed daily erythemal UV by the Lindfors model (left) and the STAR model (right) vs measured UV for Bergen for the period 2000-2004. Mean Bias Deviation (MBD) and Root-Mean-Square-Deviation (RMSD) are given, together with the one-to-one line (broken), the regression line (solid), and the correlation coefficient (Medhaug, 2007).

Medhaug (2007) also compared both the STAR and the Lindfors models to measurements at Bergen. Figure 1 shows a significantly higher RMSD for STAR (26%) than for the Lindfors model (7%). For the STAR calculations, only cloud information was used as input. The Lindfors model uses hourly global irradiance as input, making more specific information about the positions of the clouds (covering/not covering the sun) available.

3.2 Trends in modelled UV

While both ozone amount and clouds affect UVB radiation, UVA radiation is only negligibly affected by the ozone. As overall for the Norwegian stations, predominatly positive trends in UVB and erythemal UV were found due to uniform total ozone reduction. For UVA, weak positive or negative trends, in accordance with trends in cloud amount, were found.

3.3 UV radiation and biological effects

For an investigation on the relationship between biological effects and UV level in Norway, hourly UV data were reconstructed by the STARneuro model (Medhaug, 2007; Sjølingstad, 2007) for the period 1957-2005. The reconstructions were based on meteorological data from 23 Norwegian stations. As sufficient global irradiance data were available for only one station, only cloud information was used as input to STAR to account for the effect of clouds.

To investigate the relationship between skin cancer and UV level, hourly erythemal UV data were reconstructed at 17 Norwegian stations (Medhaug, 2007). Data from the Cancer Registry in Norway shows a decrease in cancer cases (malignant melanoma; MM) with increasing latitude. However, for all latitudes, the number of incidences increased steadily from 1957 to the mid 90s, with a stagnation/decrease afterwards. A peak around mid 90s with a following decrease was also found in UV. Figure 2 shows the overall decrease, both in incidences of MM and in UV, with increasing latitude (increasing station number). In addition, a predominantly positive trend in both UV and MM was found during the period 1957-2005.

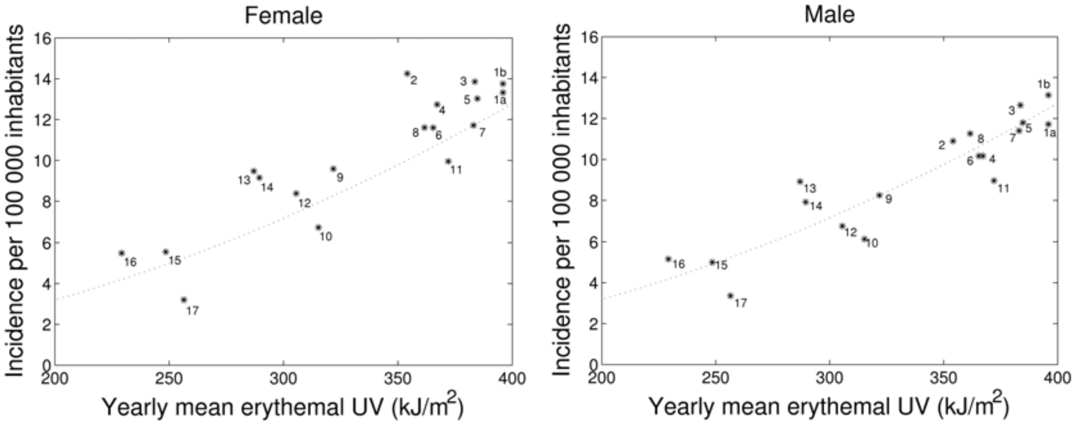

Figure 2 Rate of malignant melanoma vs annual erythemal UV for 18 stations in Norway (numbered from south to north) for the period 1957-2005 (Medhaug, 2007)

To investigate if the UV level affects the mortality of cod eggs, hourly UVA and UVB radiation, weighted with the response curve of cod eggs, were modelled for the main spawning areas of cod (Sjølingstad, 2007). Cod indices, quantifying the UV-exposure of cod eggs in the water column, were calculated for the Norwegian cod stock. A large inter-annual variability of cod index was found, but with an increasing trend during the period. As the cod stock depends on several factors, like the sea temperature and the overfishing, it is not easy to single out the effect of UV radiation on cod stock. There are, nevertheless, indications showing that the highest stocks appear at moderate UV conditions.

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