UV radiation in Norway: Measurements, reconstructions, and applications

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Introduction

During the last decades, solar irradiance has been measured in Bergen (60.40ºN, 5.39ºE), Norway. Hourly sunshine duration data exists from 1952 on, while hourly global and diffuse irradiance are available from 1965. The measurements are done by Geophysical Institute, University of Bergen. In addition, Norwegian Radiation Protection Agency (NRPA) started measurements of erythemal UV-radiation in 1996. These are stored as one-minute values. The UV measuring station in Bergen is one out of 9 Norwegian stations between latitudes 58 to 79ºN, measuring GUV (Ground UltraViolet radiation).
Because of the long time series of high quality radiation data, Bergen is selected, together with Potsdam, Davos, and Thessaloniki, as one out of four stations used for test of models for reconstruction of UV-data in the EU project ***COST726 Long term changes and climatology of UV radiation over Europe***. Situated at the western coast of Southern Norway, Bergen is representative for high latitude maritime climate.
Participation in the COST project has also initiated three recent Master theses on reconstruction of UV data and validation (Sætre, 2006; Medhaug, 2007; Sjølingstad, 2007). In the thesis of Medhaug (2007) reconstructed UV data are used for an investigation on the effect of UV on skin cancer. In the thesis of Sjølingstad (2007), the effect of UV radiation on cod eggs is investigated.
In all three theses the model STAR (System for Transfer of Atmospheric Radiation) was used for reconstruction of UV radiation (Reuder and Koepke, 2005). Additionally, in one thesis, the model of Lindfors (Lindfors et al., 2007) is used for comparison.

Observed and modelled UV radiation in Bergen

In the work of Sætre (2006), hourly erythemal UV data were reconstructed by use of the STAR model. For clear sky the model $STAR_{sci}$ was used (Reuder and Koepke, 2005), while for overall cloudiness, the $STAR_{neuro}$ was used. The last model utilizes neural network techniques, and is trained on data from Garmisch-Partenkirchen. One aim of this work was to investigate if this model is suitable also for use in the Bergen climate.
To both STAR model versions the following variable inputs were used: solar elevation, total ozone amount, and air pressure. Fixed inputs were: average continental atmosphere, aerosol optical depth (AOD) of 0.20, and ground albedo equal to 0.03. For the $STAR_{neuro}$, cloud information and global irradiance were used as additional input. Bergen is surrounded by mountains, that rise up to 10º above free horizon. Cases with solar elevation below 10º are therefore not included in the comparison, and as an albedo of 0.03 was chosen, cases with snow are also excluded.
For the clear sky cases, it was found that the ratios between measured and modelled UV had a small variation with solar elevation, but a more distinct seasonal variation.

Table 1. Ratio (R) between observed and modelled erythemal UV for different seasons in Bergen (Sætre, 2006)

Season	Winter	Spring	Summer	Autumn
R	1.04	0.97	0.89	0.94

The main reason for the seasonal variation (Table 1) is that there is a 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. For arbitrary cloud amount, it was found that the small overall overestimation found at clear sky increased with increasing cloud amount (Table 2).

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

N	0	1	2	3	4	5	6	7	8
R	.94	.94	.92	.90	.86	.84	.81	.79	.74

The overestimation found here is confirmed by another investigation (Koepke et al, 2007), where modelled UV values estimated by a total of 16 models were tested against the 4 selected stations in COST726. It can thus be concluded that if absolute values of erythemal UV for Bergen is to be estimated, the STAR model can not be used without modifications. However, by taking into consideration correction factors given in Tables 1 and 2, the STAR values can be corrected.
When trends in UV radiation are to be studied, the STAR model can be used, if it is assumed that there are no trends in cloud properties (cloud amount, cloud optical thickness).

UV radiation and skin cancer

Based on meteorological data from 17 Norwegian stations, representative for 18 counties in Norway, hourly erythemal UV has been reconstructed by the $STAR_{neuro}$ model (Medhaug, 2007) for the period 1957-2005. As sufficient global irradiance data are not available for more than one of the 17 stations, only cloud information was used as input to STAR to account for the effect of clouds. According to this work, an overestimation similar to the previous work (Sætre, 2006), was found for Bergen. However, a closer agreement was found between measurements and UV values estimated by the Lindfors model (Lindfors et.al., 2007). The cloud modifications in this model are based on calculations by the radiative transfer model libRadtran (Mayer and Kylling, 2005). Thus, this model is not trained on measurements. Additionally, as hourly global irradiance is used as input, more specific information about the positions of the clouds (covering/not covering the sun) is available. In the STAR calculation, only cloud information was used, and thus the Root-Mean-Square-Deviation (RMSD) on hourly values was 26%, compared to 7% for Lindfors model.

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 has increased steadily from 1957 to the mid 90s, but with a stagnation/decrease afterwards. A peak around mid 90s with following decrease is also found in UV.

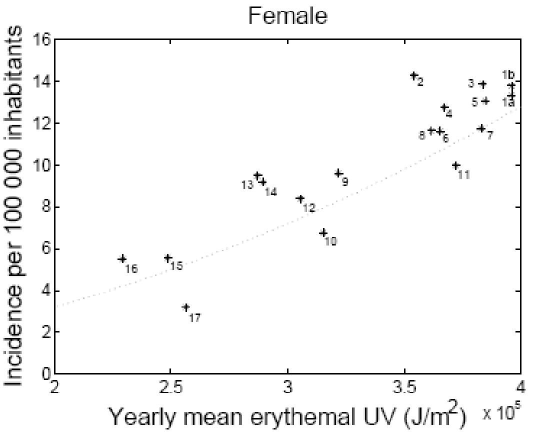

Figure 1. Rate of malignant melanoma vs annual erythemal UV for 18 stations (numbered from south to north) in Norway. Averages are given for females, for the period 1957-2005 (Medhaug, 2007)

Figure 1 shows the decrease, both in incidences of MM and in UV, with increasing latitude (increasing station number). In addition, a positive trend in both UV and MM is found during the period 1957-2005.

UV radiation and cod

For the period 1957 to 2005, hourly UVA and UVB radiation, weighted with the response curve of cod eggs, was modelled for 6 stations at the coast of Norway (Sjølingstad, 2007). The stations are representative for the 6 main spawning areas of cod. One aim of the work was to investigate if the UV level affects the mortality of cod eggs, as they are drifting passively in the sea, without any mechanism for avoiding harmful UV. Cod indices are calculated for each station for the spawning period (10. March to 10. May). The cod index depends on: weighted UV radiation at the sea surface, the transmission of UV radiation in the sea water, and the mixing of cod eggs in the water column (depends on wind stress). To calculate a cod index for the whole Norwegian cod stock, the different spawning areas are given different weight. As a function of rising temperature over time, the most important spawning areas are shifted towards the north, and this was taken into consideration.

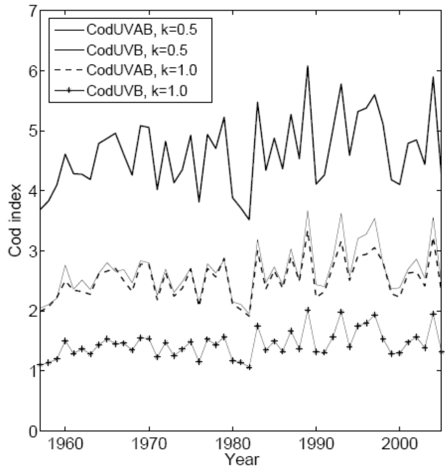

Figure 2. Total annual cod index for Barents Sea cod for the period 1957-2005. Shown as CodUVAB (UVA+UVB) and for codUVB (UVB only) for high (k=1.0) and low (k=0.5) extinction of UV in sea water. (Sjølingstad, 2007)

According to Figure 2 there is large inter-annual variability of cod index, 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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