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UV radiation and skin cancer in Norway

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ABSTRACT

A distinct increase in skin cancer incidences is observed since the registration started in Norway in the 1950s. As UV radiation is assumed to be the main risk factor for skin cancer, hourly values of the UV irradiance were reconstructed for the period 1957–2005 for 17 of the Norwegian counties (58–70°N). For reconstruction, a radiation transfer model is run with total ozone amount and cloud information as meteorological input. Reconstructed hourly erythemally weighted UV irradiances for about 5 years are compared to measurements at four stations, two stations representing the north–south extension of Norway, and two stations at about 60°N representing the eastern inland – Western coastal contrasts. The agreement between reconstructed and measured UV varies between 0% for the northernmost site to 10–15% overestimation for the other locations. For clear sky, a reasonable agreement between reconstructed and measured data was found for all stations, while for overcast, an overestimation of 10–20% was found for all but the northernmost station. Both the cancer incidences and the reconstructed UV values have a distinct north–south increase. The UV increase towards south is mostly due to increasing solar elevation. The west to east increase is much smaller, and differences in UV are due to differences in both cloud optical thickness and total cloud amount. One additional outcome from this work is that long-term UV-data are reconstructed for Norway, data that can be used in further biological and medical studies related to UV effects.

1. Introduction

Ultraviolet (UV) solar radiation is an important environmental parameter, affecting living organisms, materials, and atmospheric chemical processes [1–3]. The amount of UV radiation reaching the Earth's surface is dependent on time and location, i.e. the solar zenith angle and on various meteorological parameters like total ozone, clouds, aerosols and surface albedo. In particular since the early 1980s there has been an increased focus on UV radiation, because of the strong depletion of stratospheric ozone, especially over Antarctica during austral spring [4]. A general, but weaker, ozone depletion was also found in the Arctic and mid-latitudes [5,6]. In accordance with the decrease of stratospheric ozone an increase of UV radiation at the ground was observed [7,8].

For plants and animals, changes in UV level can cause change in primary production and altered species composition [9]. For humans, increased UV can cause damage to the eyes and immune system, and alter the probability of skin cancer [10]. Regarding UV radiation and skin cancer contradictory effects occur. While UV is a known risk factor for development of skin cancer [11,12], a higher survival rate of the skin cancer type cutaneous malignant melanoma (CMM) is found in sunny areas than at areas with less sun [13,14]. In addition, UVB is the most important source of vitamin-D, which potentially can have restraining effect on skin cancer [15].

In Norway, CMM is the second most common cancer type within the age group 30–55 years. Besides, following Australia and New Zealand, Norway has the third highest number of incidences per inhabitant in the world [16], with a steady increase, at least until 1995, since the registration of cancer started in the 1950s (Fig. 1).

The time period between sun exposure and development of skin cancer is estimated to be in the order of 10–30 years [18–20]. Investigations on the relationship between UV exposure and skin cancer occurrence for Norway therefore require long-term time series of UV radiation with appropriate spatial resolution to cover the large north–south extension of the country. As most stations started measuring UV radiation in Norway not before the 1990s [21,22] such time series are not available from direct measurements. Sufficiently long time series of UV radiation can thus only be derived by radiation modeling.

Various models of differing complexity and quality have the desired capability of long-term UV reconstruction [23–28]. All appropriate models need at least total ozone content and cloud information as basic atmospheric input. The best performing models also demand global radiation as additional input parameter as proxy for the cloud effects. For the selected reconstruction period from 1957–2005 this information is not available for Norway.

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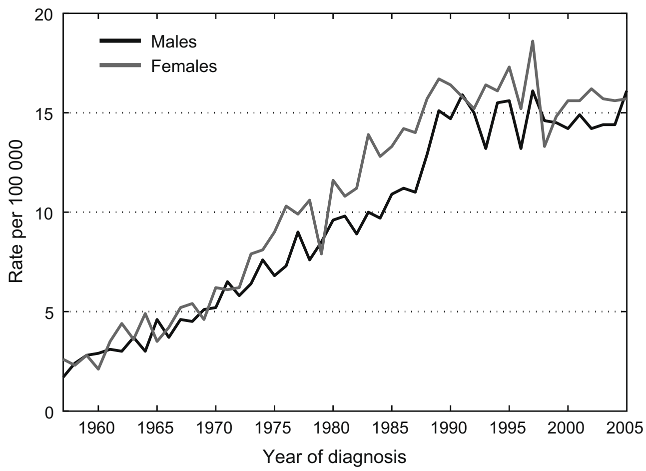

Fig. 1. Age-adjusted (according to a world standard population [17]) incidence rates for cutaneous malignant melanoma (CMM) for the Norwegian population in the period 1957–2005.

Bergen, the site with the longest global radiation data set in Norway started measurements in 1965. Other stations followed by far later and even the recent global radiation network is not able to cover all of the 19 Norwegian counties. The STAR (System for Transport of Atmospheric Radiation) model [29,30], which has been used successfully for a long-term UV reconstruction over Southern Germany [31], has finally been chosen for the determination of the presented Norwegian UV climatology. As input to the model, solar elevation, surface air pressure, cloud amount and type, cloud base height, total ozone and snow information is used.

2. Data and methods

The aim of this work is to provide a UV climatology for Norway for the past decades that is suitable for a wide range of investigations of photobiological processes. A main task was to find one station for each county, representative for the most populated areas and with sufficient long and continuous time series (1957–2005) of cloud observations. For several counties only one station was available, and for two counties (Oppland and Aust-Agder) there were no suitable stations at all. Table 1 and Fig. 5 show the selected stations for the UV reconstruction.

2.1. Radiation transfer model STAR

UV irradiances at the ground level were reconstructed by running the neural network version of STAR ($STAR_{neuro}$) [32]. The cloud effect on UV radiation in $STAR_{neuro}$ (hereafter called STAR) is described by a cloud modification factor (CMF), determined by a neural network algorithm using the type and amount of low-, medium- and high-level clouds as input. The neural network cloud algorithm of the STAR model was based on high-resolution spectral UV measurements at the German site Garmisch-Partenkirchen [33]. In this work, total ozone, surface albedo and surface pressure were used as additional observed variable input parameters for the model simulations. The required aerosol information (aerosol type, optical properties and vertical distribution) are not available for the reconstruction period, and reasonable assumptions had to be made for these parameters. The following sections describe the derivation of all required input parameter data sets from different observations.

STAR calculates spectral irradiances that can be integrated over wavelength by user-defined weighting functions. In the presented study integral unweighted UVA (315–400 nm) and UVB (280–315 nm) and erythemally weighted UV radiation (ERY, weighted by the CIE function for the sensibility of the human skin, [34]) have been estimated once each hour. This was done for all counties in Norway for the period 1957–2005. The start of the reconstruction period was chosen in accordance with the improved availability of total ozone data due to the International Geophysical Year in 1957 and the availability of cloud observations. The reconstructed UV-data from STAR are instantaneous values in W/m^2 which have been subsequently integrated into daily, monthly and yearly UV exposure values in J/m^2 for the further analysis.

2.2. Input data to the STAR model

The solar elevation is predetermined by date, time and the location of the station. The altitude of the site and its effect on Rayleigh scattering is represented by the surface air pressure. Other input parameters have to be worked out in more detail.

2.2.1. Clouds

The cloud information required as input for the STAR model, is both the cloud amount and the cloud type for low, medium-high and high-level cloud layers. As this information is not directly observed by the synoptic network, a corresponding algorithm was developed and applied. It uses the routine cloud observations

Table 1
Location of the selected synoptic stations used for the UV reconstruction.

Nr	Station	County	Lat (°N)	Lon (°E)	h (m)	Period
1	Kjevik	Vest-Agder	58.20	8.07	12	1957–2005
2	Sola	Rogaland	58.88	5.64	7	1957–2005
3	Færder Fyr	Vestfold	59.03	10.53	6	1957–2003
4	Tveitsund	Telemark	59.03	8.52	252	1957–2005
5	Rygge	Østfold	59.38	10.79	40	1957–2005
6	Lyngdal	Buskerud	59.91	9.52	288	1957–2005
7	Oslo[a]	Oslo	59.94	10.72	94	1957–2005
8	Gardermoen	Akershus	60.21	11.08	202	1957–2005
9	Bergen	Hordaland	60.38	5.33	12	1957–2005
10	Takle	Sogn og Fjordane	61.02	5.50	38	1957–2005
11	Rena	Hedmark	61.16	11.44	240	1958–2005
12	Tafjord	Møre og Romsdal	62.23	7.42	15	1957–2005
13	Ørland	Sør Trøndelag	63.70	9.60	10	1957–2005
14	Værnes	Nord Trøndelag	63.46	10.93	12	1957–2005
15	Bodø	Nordland	67.27	14.43	11	1957–2005
16	Tromsø	Troms	69.65	18.95	100	1957–2005
17	Sihccajavri	Finnmark	68.75	23.53	382	1957–2005

[a] Only used for model validation due to missing cloud details in the period 1981–1997.

(see [35]) of total cloud amount (NN), amount of the lowest cloud type observed (NH), and the types of low (CL), medium-high (CM) and high clouds (CH) and converts it to the appropriate STAR input. For details see [36].

2.2.2. Total ozone amount

Both the spatial distribution and the temporal availability of total ozone measurements are limited. For Norway there have been only six measurement sites in the period 1957–2005, alone four of them situated on Svalbard. All sites have only incomplete time series (e.g. due to weather conditions) and most stations have only been operational for shorter time periods.

Since ozone mainly depends on the large scale structures in the stratosphere it is possible to extract stations over a large area and interpolate between them. Twenty stations from the WOUDC (World Ozone and Ultraviolet Radiation Data Center) database [37], inside the area limited by 55°N (Denmark) in the south, 80°N (Svalbard) in the north, 10°W (England) in the west and 40°E (Russia) in the East, were used (Table 2). A modified Cressmann interpolation scheme [38], accounting for the distance of the ozone measuring site to the relevant Norwegian location, has been used to interpolate the ozone measurements for each county. Details on the method can also be found in [36].

2.2.3. Aerosols

The main UV relevant aerosol properties, i.e. aerosol optical depth, single scattering albedo and vertical aerosol distribution are not available operationally. Therefore reasonable assumptions on aerosol types and corresponding profiles have to be made. Norway has a long coast line, and about 75% of the counties have a climate strongly influenced by the sea. In addition, population density and industrial emissions are rather low. This results in mainly low to moderate aerosol load. Consequently the aerosol type was set to maritime clean (mc) for all reconstruction sites [39].

For each station, the aerosol optical depth at 550 nm was prescribed with seasonal dependent values shown in Table 3, chosen according to [40]. For all stations, winter is defined as December–February, Spring as March–May, Summer as June–August, and Autumn as September–November. For Summer the boundary layer depth was set to 2 km, while for the rest of the year 1 km was used.

Table 2
Location and time period for the selected stations used for the ozone interpolation. Not all time series are complete throughout the indicated periods.

Station (WOUDCnr)	Country	Lat (°N)	Lon (°E)	h (m)	Period
Eskdalemuir (39)	GBR	55.32	−3.20	242	1957–1963
Moscow (116)	RUS	55.75	37.57	187	1974–2004
Århus (34)	DNK	56.17	10.20	53	1957–1988
Riga (121)	LVA	57.19	24.25	7	1973–1999
Tahkuse (350)	EST	58.52	24.94	23	1995–1998
Norrkøping (279)	SWE	58.58	16.15	43	1988–2005
Uppsala (54)	SWE	59.85	17.52	15	1957–1966
Oslo (165)	NOR	59.91	10.72	90	1969–1998 2004–2005
St. Petersburg (42)	RUS	59.97	30.30	74	1973–2003
Lerwick (43)	GBR	60.10	−1.18	80	1977–2005
Joikoinen (404)	FIN	60.81	23.50	103	1999–2001
Vindeln (284)	SWE	64.24	19.77	225	1991–2005
Arhangelsk (271)	RUS	64.58	40.50	0	1974–2003
Sodankylä (262)	FIN	67.33	26.50	179	1988–2005
Murmansk (117)	RUS	68.97	33.05	46	1973–2003
Tromsø[a](52)	NOR	69.65	18.95	100	1957-2005
Svalbard Hornsund (189)	NOR	77.00	15.55	11	1970–1983
Longyear (44)	NOR	78.22	15.58	1	1950–1966 1984–1993
Ny Ålesund (89)	NOR	78.93	11.88	243	1966–1997
Murchinson Bay (46)	NOR	80.00	18.00	0	1958

[a] Andøya is used in the period 2002–2005 (69.30°N, 16.15°E).

Table 3
Aerosol optical depth at 550 nm chosen for the different seasons of the UV reconstruction.

	Winter	Spring	Summer	Autumn
Southern stations	0.10	0.15	0.20	0.15
Northern stations	0.05	0.05	0.10	0.05

2.2.4. Spectral surface albedo

Natural surfaces usually have a surface albedo well below 0.1 in the UV spectral range. In case of snow cover, however, the ground albedo can reach values of above 0.8 (see e.g. the review paper [41]). The actual reflectance of a snow covered surface is strongly dependent on snow depth, snow age and the presence of tall vegetation and buildings [42]. In accordance with relevant publications [43,44,41], snow cover and snow depth observations have been converted into albedo values by the simplified method described in the following. Snow depth and snow cover are observed by the Norwegian Meteorological Institute once each day for most of the stations selected for reconstruction (see [36] for detailed information). Snow cover is reported as number of quarters of the ground covered by snow. Both observations were used to estimate the regional spectral surface albedo. For snow free conditions, the spectral ground albedo is set to 0.03. For snow cover of 1/4, 2/4 and 3/4 the albedo is set to 0.1, 0.2 and 0.3, respectively. For complete snow covered ground, the snow depth dependence of the ground albedo is given in Table 4 according to [43,44,41].

2.3. UV measurements

The Norwegian UV monitoring network [21] is operated by The Norwegian Radiation Protection Authority (NRPA) and the Norwegian Pollution Control Authority (SFT) via the Norwegian Institute for Air Research (NILU). It consists of eight measuring sites between 58°N (Kjevik) and 79°N (Ny-Ålesund). The first measuring station, Oslo, started the measurements in February 1994. In 2000 the station in Tromsø was closed down and the instruments were moved to Andøya (approximately 120 km to the southwest).

The network operates multi-channel GUV (Ground-based UltraViolet radiometer) 541 from Biospherical Instruments [45–48,22,49]. These instruments measure irradiance within five wavelength bands in the UV-region. The bandwidth is approximately 10 nm with the center at 305 nm, 313 nm, 320 nm, 340 nm and 380 nm. The GUV instruments are fully automatic and log the measured data every minute. To maintain high quality on the data, a standard instrument is calibrated once a year, and in a period every summer this instrument is run in parallel with the instrument of each station [50,22]. A possible drift of the sensors between the annual calibrations is corrected for linearly. The overall uncertainty of the UV measurements is estimated as better than ±6% [22].

Based on the measured UV-data of the different channels, various radiation quantities such as biological effective irradiance,

Table 4
Snow depth dependent albedo for completely snow covered surface used in the UV reconstruction.

Snow depth (SD)	Albedo (α)
<5 cm	0.5
5 cm < SD < 20 cm	0.6
>20 cm	0.8

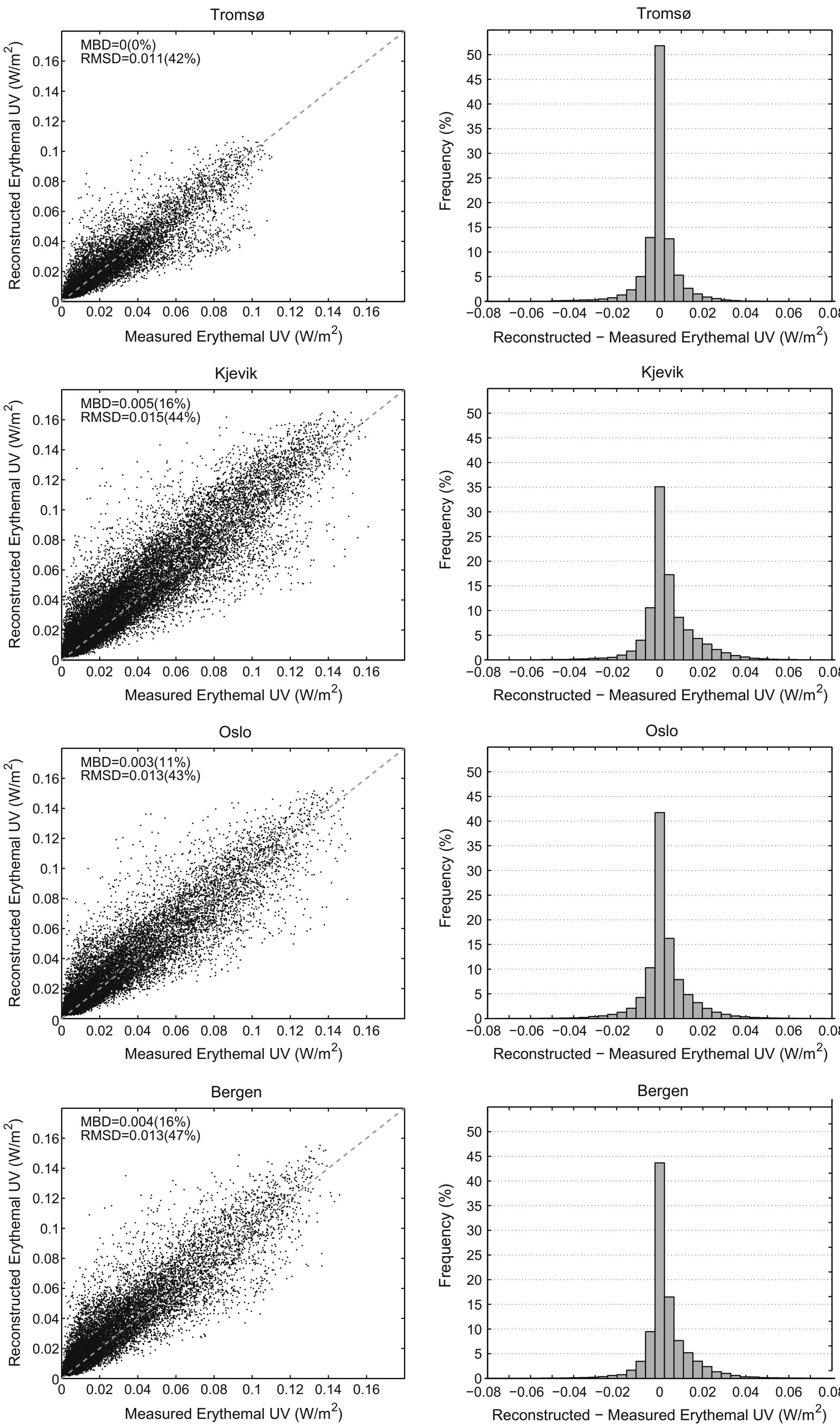

Fig. 2. Left: reconstructed vs. measured hourly erythemal UV for Tromsø, Kjevik, Oslo and Bergen for solar elevation >10°. The 1-to-1 line (broken) is given, together with the Mean Bias Deviation (MBD: reconstructed – measured) and the Root Mean Square Deviation (RMSD). Right: frequency distribution of reconstructed – measured erythemal UV for Tromsø, Kjevik, Oslo and Bergen. Bin-size: 0.0044 W/m^2.

UV-dose and UV-index are calculated. Hourly CIE-weighted UV irradiances are used for the comparison with the modeled data in Section 3.1.

3. Results

Based on the input data described above, hourly values of the erythemal UV exposure have been reconstructed for all counties in Norway for the period 1957–2005. As a quality check these high-resolution data have been compared to measurements at four sites of the Norwegian UV radiation network. To account for the large north–south extension of Norway and the differences in coastal and continental climate in Southern Norway, the following four stations have been selected. Tromsø (1996–1999) as the northernmost, and Landvik (1996–2004) as the southernmost stations, and the two stations at about 60°N, representing the Eastern inland part (Oslo; 1998–2002) and the Western coastal region (Bergen; 2000–2004). For investigations of the annual variability and long-term trends in UV exposure, the hourly values have been integrated on a yearly basis. Periods of missing cloud observations have been filled on a daily basis by climatological average values for the corresponding station and representative for the corresponding decade. For details about this method see [36].

3.1. Comparison with measurements

The left column of Fig. 2 shows a comparison between reconstructed and measured erythemally weighted UV for Tromsø, Kjevik, Oslo and Bergen for solar elevation above 10°. Cases of lower solar elevation are excluded due to potential screening effects of an elevated horizon on the measured data [51]. Note that Oslo is only used for model validation due to missing cloud information in the period 1981–1997.

For all stations, a correlation coefficient of about 0.9 is found. For the southern stations, i.e. Kjevik, Oslo and Bergen, the model gives an overestimation of 11–16% (Fig. 2; left) which agree with the findings of [52,27]. However, for the northernmost station, Tromsø, the Mean Bias Deviation (MBD) between modeled and measured values is zero. This is also evident in the right part of the figure, which shows the distribution of reconstructed – measured values for the different stations. For Tromsø the deviations are symmetrically distributed around 0, with more than 50% of the deviations between ±0.0022 W/m^2. Kjevik, Oslo and Bergen have a distibution skewed toward positive anomalies, with only 35–44% of the values within ±0.0022 W/m^2.

According to the left column figures there is a significant scatter with a Root Mean Square Deviation (RMSD) of 42–47% for the various stations. One reason for these large RMSDs is that only cloud information is used as input to the STAR model as shown in [36]. The model is also capable to use global radiation as additional input, and thus a more specific information about the position of the clouds relatively to the sun would most probably give smaller RMSDs. As only one of the 17 stations in Norway selected here have global radiation data, only cloud information is used in this work (since the focus is making a climatology for the whole country).

A division into solar elevation intervals of 10° width (not shown), showed correlation coefficient between 70% and 80%, increasing with increasing solar elevation. The MBDs for the differ-

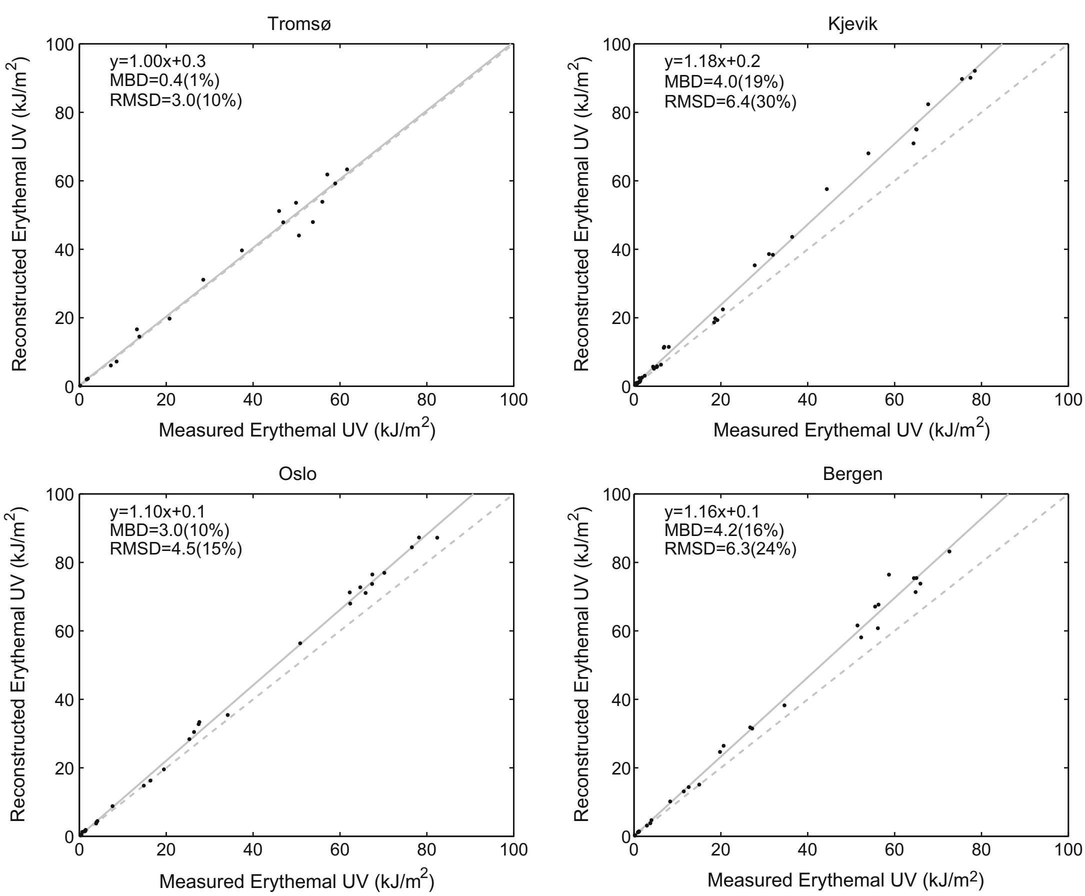

Fig. 3. Reconstructed vs. measured monthly erythemal UV for Tromsø, Kjevik, Oslo and Bergen for solar elevation >10°. The 1-to-1 line (broken) and the linear regression line (solid) is given, together with the linear regression equation, the Mean Bias Deviation (MBD: reconstructed – measured) and the Root Mean Square Deviation (RMSD). The monthly mean values might deviate from monthly doses since they are composed only from times of available measurements.

ent solar elevation intervals are between 10% and 20% for the three southern stations and negligible (±1%) for the northernmost station. The overestimation is largest for intermediate solar elevations. The RMSD is decreasing from approximately 50% for solar elevation between 10° and 20° to approximately 35% for the highest solar elevation at all stations.

During cloud free conditions, ozone has the dominant effect on the radiation transfer, while for overcast, the cloud effect is dominant. As the northern station had better agreement between modeled and measured data than the southern stations it is of interest to analyze if these differences are similar both in clear sky and overcast conditions. Therefore, the data were divided into clear sky and overcast cases, based on total cloud amount data [36]. To be sure that the effects from topography are excluded, only measurements with solar elevation above 20° is used in this study. From the clear sky cases, there is only a slight overestimation for all stations (1–7%), with RMSDs between 15% and 22% and correlation coefficients between 0.93 and 0.97. For overcast conditions there is, however, an overestimation of 11–20% at the southern stations, while there is only a slight underestimation of 5% at Tromsø. The RMSD is almost equal for all stations, between 50% and 60%.

According to Fig. 2, there is a significant scatter when reconstructed and measured hourly values of erythemally weighted UV are compared. The similar comparison for monthly values is shown in Fig. 3 with a correlation coefficient of ≈0.99. The monthly values show an overestimation of 1–19% which is increased by 1% if low solar elevations (<10°) are included.

When deviations between modeled and measured data are to be discussed, the fact that the STAR model is trained on data from Garmisch-Partenkirchen is to be mentioned. Thus regional differences in macrophysical (cloud type, cloud thickness, cloud base height) and microphysical (liquid water content, droplet size) cloud properties between this central European station and the Norwegian stations can be expected to affect the results. In addition, Garmisch-Partenkirchen is located in a valley surrounded by high mountains, limiting the sky-view to angels larger than 18° above the horizon in the south. This might also influence the reconstructed values at low solar elevations.

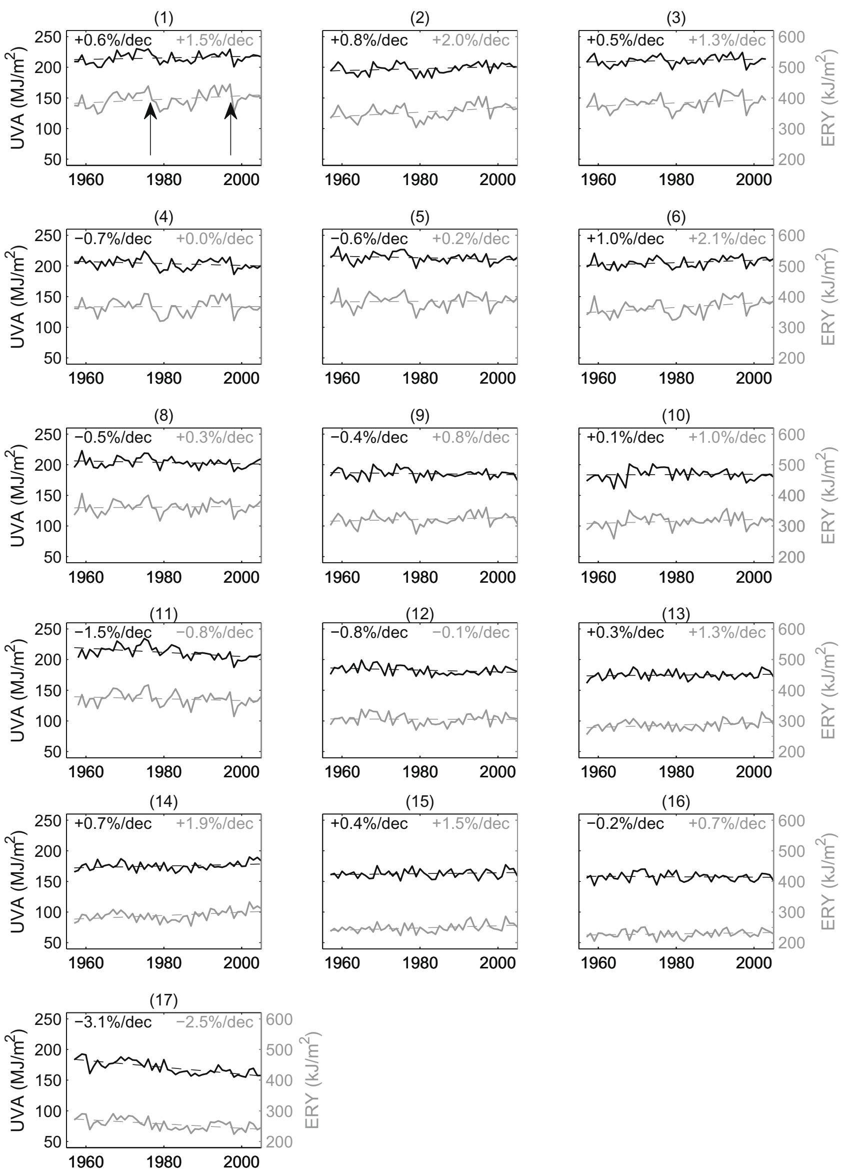

Fig. 4. Yearly sum (solid lines) and linear trends (dashed lines) of UVA (black) and ERY (grey) for the synoptic stations listed in Table 1. Decadal trends for each station are shown above time series. Numbers on top of each graph represent the stations listed in Table 1 and plotted in Fig. 5. Arrows for station 1 indicate distinct minimum–maximum constellations for the southern stations 1–11 (see text for more explanation).

Even though the results from the comparison shows mainly an overestimation, the focus of this study is more on the trends and variations instead of absolute values. Therefore, if no significant changes in the above mentioned cloud properties is assumed, the modeled data are a suitable tool for this investigation. Changes in cloud amount are taken into account by the use of cloud cover observations as model input.

3.2. Temporal and spatial variations

Fig. 4 shows the reconstructed annual exposures for UVA (black lines) and erythemally weighted UV (ERY, gray lines) together with the linear trend lines for the period 1957–2005. A distinct year to year variability that is similar in both wavelength ranges for each of the stations, indicates the UV dependency of cloudiness. Besides, the effects of the large scale synoptic situation are expressed by a similar behavior for stations in certain regions of Norway. As an example, for all southern and south eastern stations (1–11) rather similar structures of the time series is seen, e.g. distinct minimum–maximum constellations (1976–1979, 1997/1998; marked by arrows for station 1 in Fig. 4).

The latitude dependency of solar elevation leads to a distinct north–south gradient of radiation over Norway. For average UVA the increase from around 150 MJ/m^2 in the north to about 220 MJ/m^2 in the south corresponds to an enhancement close to 50%. For ERY the gradient is even stronger, with average values rising from 220 kJ/m^2 to 400 kJ/m^2, nearly a doubling of erythemally effective UV radiation from north to south of Norway. The main reason for this difference is that the strong absorption of ozone in the UV wavelength range below 320 nm increases with increasing pathlength of the photons through the atmosphere, i.e. with decreasing solar elevation. The increase in Rayleigh scattering with decreasing solar elevation is less important. The data also indicate an east–west gradient in southern Norway. The stations at the Western coast of Norway (e.g. 9 and 10) show radiation values that are 15–25% lower than at station 11 in the east at the same latitude. This feature can mainly be explained by variations in cloud properties. The prevailing westerlies transport moist air to the West coast of Norway, causing orographic lifting and production of dense clouds. In the east, a more continental climate is responsible for fewer and less dense clouds.

Fig. 4 also gives the linear trend in % per decade for UVA and ERY. Fig. 5 presents the decadal trends for the reconstructed data for the annual exposures of UVA, UVB, and ERY, together with the corresponding trends of the governing parameters total cloud cover (NN) and total ozone column (O3) for 16 of the Norwegian counties (Table 1). The ozone dependency of integral radiation quantities in the UV can be expressed by a so-called radiation amplification factor (RAF), a number that gives the percentage increase in the corresponding radiation integral when the total ozone content decreases by 1% [53]. With an RAF of 0.03 [54], UVA is nearly unaffected by the total ozone amount, and thus

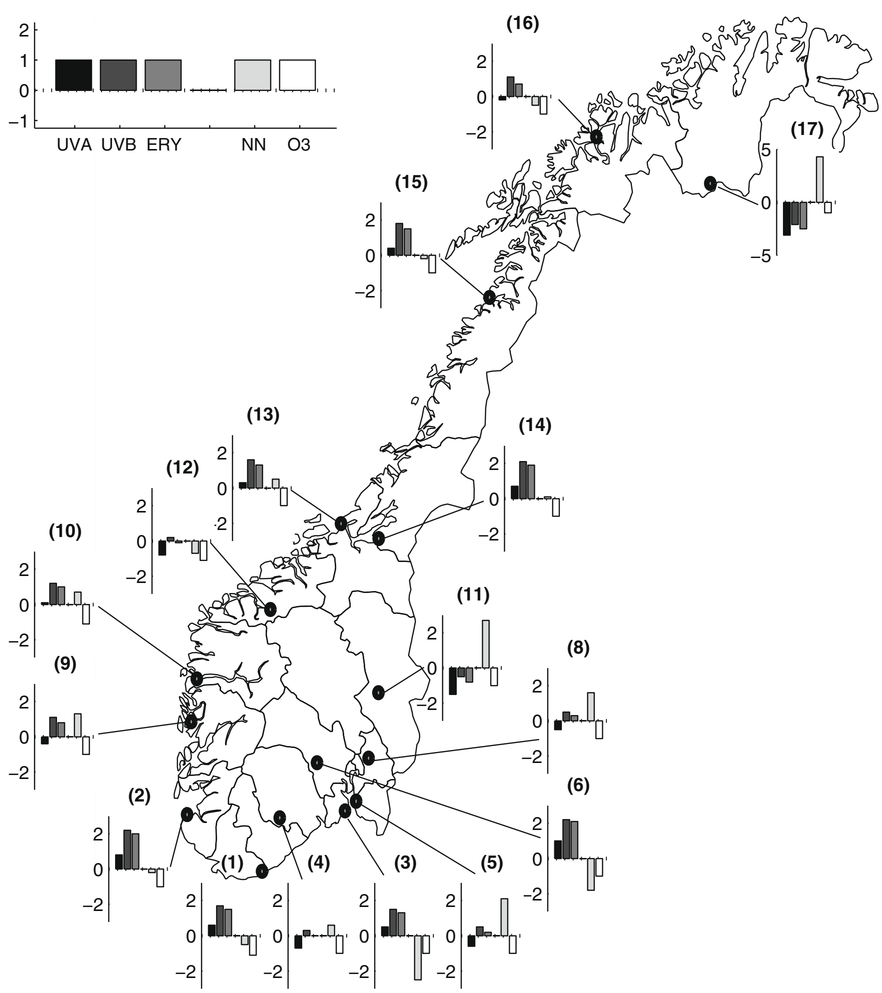

Fig. 5. Percentage decadal trends in UVA, UVB, erythemal UV (ERY), total cloud amount (NN) and total ozone amount (O3) for 16 Norwegian stations (indicated by black dots on the map and listed in Table 1). Note different scaling on the *y*-axis for station 17.

gives a good proxy for the cloud effect on the annual radiation exposures.

Fig. 5 shows a general and nearly uniform total ozone reduction of around 1% per decade for the period 1957–2005. From this and the corresponding RAF for ERY (between 1.1 and 1.3 [54]), a positive trend slightly above 1% per decade should be expected as pure ozone effect. A deviation from this numbers can then mainly be addressed to cloud influence. For ERY nearly all stations (except 11,12, and 17) show positive trends (up to 2% per decade). The mainly positive trends found in ERY are about 1% smaller for UVA, and for 8 of the 16 stations even a negative trend is found (up to 3% pre decade for station 17). The trend in cloud cover is highly variable over Norway, positive and negative values are nearly evenly distributed. There is a general tendency towards higher variability in the eastern inland part of Norway, where the trends show distinctly higher absolute values, reaching the abso-

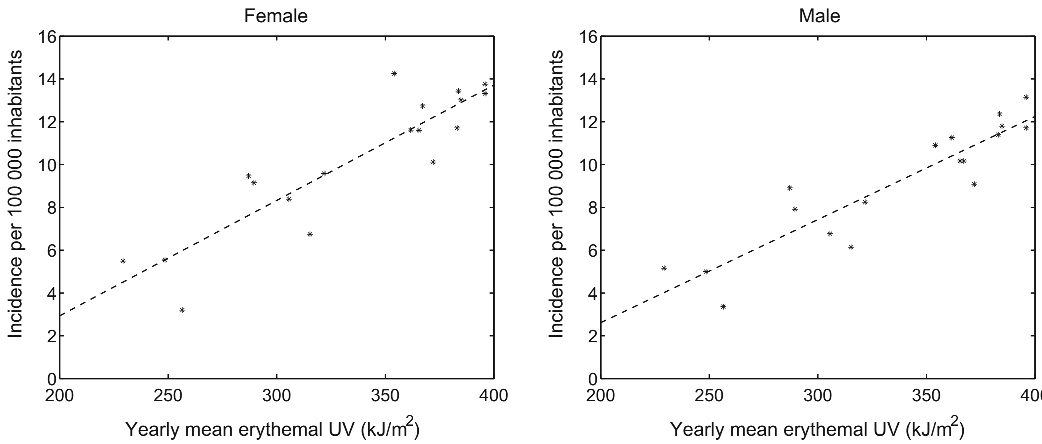

Fig. 6. Mean incidence rate of malignant melanoma vs. mean erythemal UV for the period 1957–2005 for female (left) and male (right) for 18 counties. Dotted line shows linear regression.

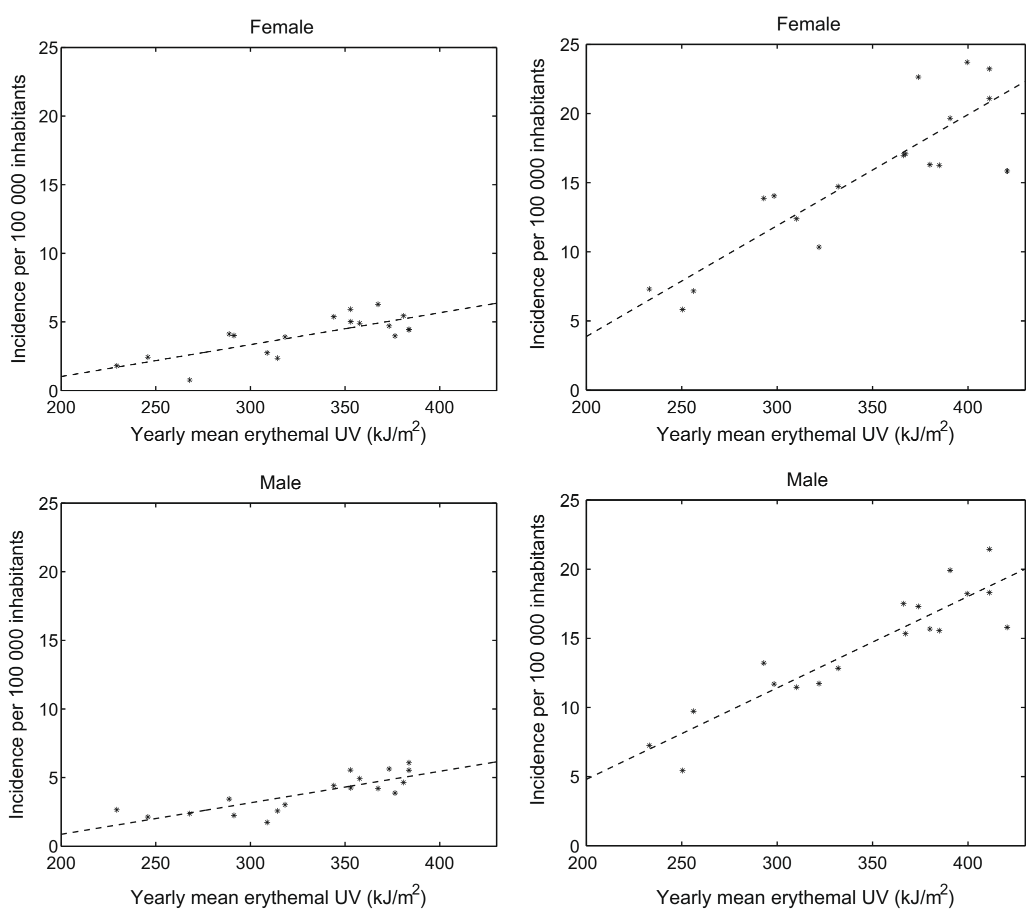

Fig. 7. Mean incidence rate of malignant melanoma vs. mean erythemal UV for the period 1960–1970 (left) and 1990–2000 (right) for female (upper) and male (lower) for 18 counties. Dotted line shows linear regression.

lute maximum of close to +5% per decade for Sihccajavri (17) in the north.

3.3. UV vs. skin cancer

Fig. 6 shows the mean annual incidence rate of malignant melanoma vs. mean erythemal UV for the period 1957–2005 for the Norwegian counties. There seems to be a close correlation between the amount of cancer incidences and the UV radiation exposure. The same can be seen both for UVA and UVB (not shown). The data points are clearly divided into three clusters. The three northern stations are found in the lower left part of the figure, as they have the lowest amount of both UV radiation and cancer incidences. According to Fig. 5, there is a long north–south distance between the northern reconstruction sites and the southern ones. The second cluster (five stations) consists of the middle and western part of Norway (except Rogaland), having both intermediate level of UV and intermediate number of cancer incidences. The southern and eastern part are in the last cluster (10 stations), with both the highest radiation level and the highest occurrence of cancer. The high UV values in east coincide well with the less dense clouds occurring there.

According to Fig. 7, for most stations only a small increase in erythemal UV is found from the period 1960–1970 to the period 1990–2000. However, a distinct increase is seen in incidences of malignant melanoma from the first to the second period. Note that the ratio between skin cancer incidences in southern and northern locations is approximately 2.5 for both periods. For most stations there has been a leveling of skin cancer after 1990 which is reflected in Fig. 1. Since there has been an increase in incidences but not a distinct increase in UV, other factors than UV radiation also have to be taken into consideration when the increase in incidences of skin cancer is to be discussed.

One reason for the marked increase in skin cancer is an earlier detection of the melanomas due to increased awareness and focus on the problem, and this is seen in an increased 5 years survival rate [55]. Besides, even though the local amount of UV radiation is known, the individual exposure dose for a human being is not known. During the period studied here mobility and vacation habits has changed. Besides, there have been changes in clothing fashions, sun bath habits and systems for sun protection.

4. Summary and conclusions

Since the registration of skin cancer started in Norway in the 1950s there has been a steady increase in cancer incidences. As UV radiation is assumed to be the main risk factor for skin cancer long-term radiation data are needed for a study of the relationship between cancer incidences and the UV radiation. Thus, due to the sparse network and to the short time series of measured UV-data, data were reconstructed for 17 of the Norwegian counties (58–70°N) for the period 1957–2005.

For a test between modeled and measured UV-data four measuring stations were selected, two stations representing the north–south extension of Norway (58 and 70°N) and two stations representing the east–west (inland-coastal) contrasts at 60°N. Overall, a good agreement was found for the northernmost station, while for the three southern stations the model overestimated the UV radiation by 10–15%. A study of the clear sky situations showed a reasonable agreement between reconstructed and measured data for all stations. For overcast situations, an overestimation of 10–20% was found for all but the northernmost station. This overestimation is probably due to the cloud parameterisation of the model, as the STAR model used here was developed upon data from Garmisch-Partenkirchen.

Both the cancer incidences and the reconstructed UV values have a distinct north–south increase and a less distinct west–east increase. While the UV increase toward south is mostly due to increasing solar elevation, the UV increase toward east is due to a combined decrease in total cloud amount and in cloud optical thickness.

This work shows that the regions with high frequency of skin cancer coincidence with the regions of high UV radiation levels. As the study do not include other factors important for the development of skin cancer, like changes in mobility, vacation habits, sun bath habits, clothing fashions, etc., this study only indicates the relationship between skin cancer and the local UV level.

One major outcome from this work is also that long-term UV-data are reconstructed for Norway, and the data can thus be used in a large variety of other applications. Besides, as the input data to the model and the model setup are done, the model can easily be run again with e.g. other biological weighting functions. Hence, this will then be a helpful tool for further biological and medical studies related to UV effects.

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