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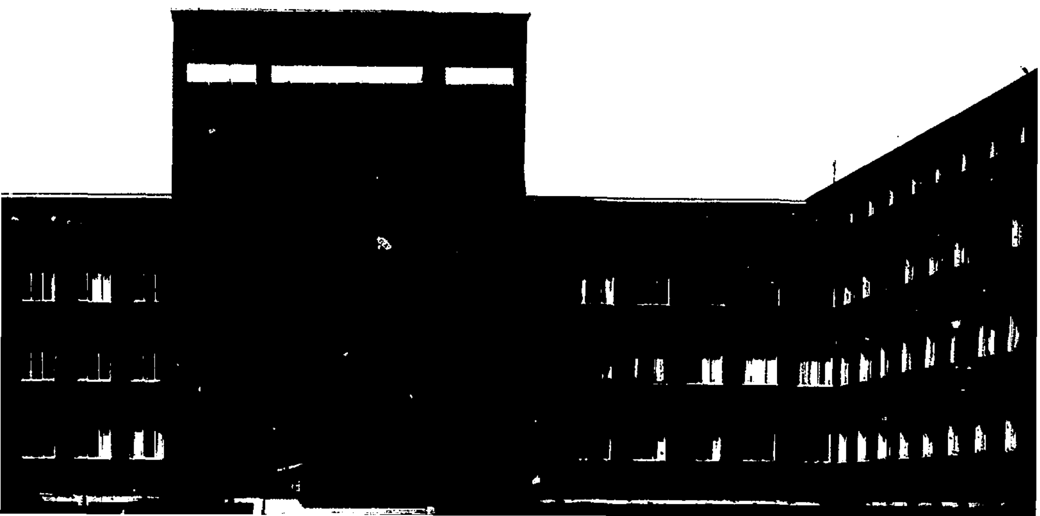

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Abstract

Effective UV-doses were calculated based on the integrated product of the biological action spectrum (the one proposed by IEC was adopted) and the solar radiation. The calculations include absorption and scattering of UV-radiation in the atmosphere, both for normal ozone conditions as well as for a depleted ozone layer.

The effective annual UV-dose increases by approximately 4 percent per degrees of latitude towards the Equator. An ozone depletion of one percent increases the annual UV-dose by approximately 1 % at 60° *N (increases slightly at lower latitudes). A large depletion of 50 % over Scandinavia* (60° *N) would give these countries an effective UV-dose similar to that obtained, with normal ozone conditions, at a latitude of* 40° *N (California or the Mediterranean countries).*

The Antarctic ozone hole increases the annual UV-dose by 20 to 25 percent which is a similar increase as that attained by moving 5 to 6 degrees of latitude nearer the Equator.

The annual UV-dose on higher latitudes is mainly determined by the summer values of ozone. Both the ozone values and the effective UV-doses vary from one year to another (within ±4 % *). No positive or negative trend is observed for Scandinavia from 1978 to 1988.*

Introduction

Since ozone effectively absorbs solar UV-radiation it is generally accepted that any depletions of the ozone layer may have a deleterious effect on the life on earth. It is therefore important with a continuous observation of the ozone layer in order to record all changes which have a natural origin as well as those proposed due to human activities (for example the release of chlorofluorocarbons, CFCs).

In 1985 Farman et. al. observed a significant springtime depletion in the ozone layer over Antarctica (often called an *"ozone hole"*) which coincides with the polar vortex. Furthermore, a recent NASA-report (The Ozone Trends Panel, 1988) indicated a small negative trend for the ozone layer also for the Northern Hemisphere. Thus, an analysis of the Dobson ozone data for the period 1969 to 1986 suggested a depletion of 2 to 3 percent in that period (see Table 1 below).

Several atmospheric models have been proposed (Solomon 1988, Brasseur and Hitchman, 1988) which suggest a depletion of the ozone layer in the coming decades due to the effect of trace gases from human activities such as CFCs, CH_4, N_2O and CO_2. The extent of the proposed depletion varies significantly from one model to another mainly because different trace gases and the concentrations they may reach are considered. The total reduction the next 50 years in the different scenarios is assumed to be from none to approximately 15 percent.

Any change in the ozone layer will undoubtedly result in a change in the *"effective"* or the *"biological"* UV- dose. Based on biological action spectra and the absorption and scattering of UV-radiation in the atmosphere we have calculated *"effective UV-doses"* with the purpose to evaluate the health effects of the proposed ozone layer depletions as well as of ozone holes similar to that in Antarctica. Furthermore, the dose effect curves for the incidence of the different types of human skin cancer are considered (Henriksen et. al. 1988).

Materials and Methods

The efficiency of the UV-radiation varies with the wavelength according to the action spectrum. Whenever mixed radiation is applied the effective UV-dose is defined as the integrated product of the action spectrum and the source spectrum. The doserate and the total dose are given by the expressions (1) and (2) respectively.

$$dD/dt = \int_{290}^{400} A(\lambda) \cdot I(\lambda)\, d\lambda \qquad (1)$$

$$D = \int_{time} \int_{290}^{400} A(\lambda) \cdot I(\lambda, t)\, d\lambda\, dt \qquad (2)$$

A(λ) is the action spectrum of the particular biological effect studied. I(λ) is, in this work, the solar radiation at sea level. The solar radiation varies both with the ozone layer and the solar zenith angle (which implies; time of the day, part of the year as well as the geographical latitude). These conditions are taken care of when total doses are considered and included in the expression $I(\lambda, t)$.

The products in expressions (1) and (2) are integrated over the wavelength region 290 to 400 nm. For large ozone depletions (more than 70 to 80 percent) UV-radiation below 295 nm become effective and the integrations are extended to 220 nm.

In the present calculations the double integral is approximated by a double sum with $\Delta\lambda = 1$ nm and $\Delta t = 1$ hour.

The total effective UV-dose for a full year is calculated, but shorter periods like the summer months may be chosen.

The action spectrum

The action spectrum to be used would preferably be a general one for "UV-damage", implying that the different deleterious effects are included. The action spectra for the formation of pyrimidine dimers, for cell killing, mutagenesis, skin erythema, delayed pigment formation in human skin as well as cancer in mouse epidermis are all quite equal *(Human Exposure to Ultraviolet Radiation;* eds. Passchier and Bosnjakovic, 1987). All spectra consist of a UVB component with a shape (that is effect versus wavelength) similar to that for the DNA absorption, and a much smaller (by a factor 10^3) UVA component.

The action spectrum used in these calculations is that suggested by the International Electrotechnical Commission (IEC). This action spectrum, which is in close agreement with the human skin erythema spectrum (Parrish et. al 1982), is divided in three regions with the following weight factors (W);

Wavelength (nm)	Weight factor
up to 298	$W = 1.0$
299 - 328	$\ln W = 0.2164\,(298 - \lambda)$
329 - 400	$\ln W = 0.0345\,(139 - \lambda)$

These weight factors are equivalent to the quality factor used in the dosimetry of ionizing radiation going from absorbed dose (in gray) to biological or dose equivalent (in sievert).

The Solar Radiation

In the expression $I(\lambda\ ,t)$ we have included the direct solar radiation as well as all orders of scattered light (Rayleigh scattering) from the atmosphere. Recently Stamnes et. al. (1988) introduced a new numerical implementation of the discrete ordinate method for radiative transfer commonly ascribed to Chandrasekhar (1960). We used this method for vertically inhomogeneous layered media. Thus, the model-atmosphere (US Standard Atmosphere 1976) was divided in 39 homogeneous layers with a thickness of 2 km. The optical parameters (World Meteorological Organization, 1985) were allowed to vary from one layer to the other. The ozone depletions involved were assumed to be the same percentage in all layers. The effect of the ozone hole in Antarctica was also calculated for a depletion concentrated to the region between 14 and 24 km in agreement with the latest observations.

Ozone Measurements

The ozone values used in these calculations are the zonal averages for the Northern Hemisphere. Furthermore, the observed Norwegian values for the region 60° N to 80° N have been used. We have three ozone stations (Oslo and Tromsø in mainland Norway and Spitsbergen on 79° N) which are equipped with the traditional Dobson instrument. We have a long record of measurements (in Tromsø they extend back to July 1935).

In the present calculations the effective UV-doses are given relative to that obtained for 60° N (Oslo) with normal ozone conditions (ten year average of the ozone measurements).

Results and Discussion

Normal Ozone Conditions

In Fig. 1 is shown the effective UV-doserate as a function of time during the day for two different days (June 22nd and August 22nd). The sea level radiation at two different places; 60° N (Scandinavia) and 40° N (corresponding to San Francisco or Mallorca) are chosen. The differences are due to a combination of the solar zenith-angle (which includes time of the day and year as well as the latitude) and the thickness of the ozone layer.

Two characteristic properties are evident from Fig. 1. In the first place, the doserate differences with latitude reach their maximum values at noontime and seem to disappear and even become reversed early in the morning and late in the afternoon. Furthermore, the noontime differences attain their smallest values at mid-summer. Thus, at summer solstice the doserate at 40° N is 67 % larger than that at 60° N, whereas two months later this difference has increased to 101 %.

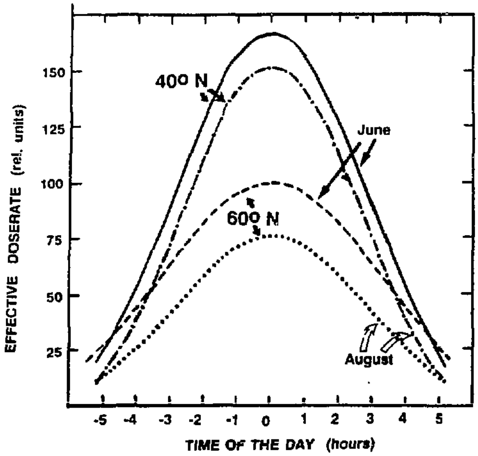

Figure 1: *Effective UV-dose as a function of time during the day. Time zero (0) is midday or noon. The dashed and dotted curves are valid for a latitude of 60° N (for example Oslo, Norway or Leningrad, USSR). Two different days are chosen; June 22nd (summer solstice and maximal doserate for the year) and August 22nd. Normal ozone values (zonal averages) are used, which for 60° N are 350 DU (dobsonunits) in June and 300 DU in August. For 40° N the repective values are 330 DU and 300 DU.*

The ozone layer varies considerably, not only throughout the year (at 60° N the annual variation is approximately 40 % with the lowest value in November), but also with the geographical latitude. Thus, the annual average for 60° N is approximately 11 % larger than that for 40° N and about 37 % larger than that for the Equator. This global distribution of ozone has significant influence when the annual UV-doses are calculated.

In Fig. 2 is presented the annual effective UV-dose as a function of the geographical latitude. The dose for 60° N (Oslo) is set equal to 100.

The combination of the solar zenith angle and the ozone layer yield the particular shape of the curve. The curve in Fig. 2 is valid for the Northern Hemisphere since the ozone values for this area were used. The ozone distribution and values on the Southern Hemisphere are somewhat different and the dose versus latitude curve may therefore be slightly different. In general, the data in Fig. 2 demonstrate that the effective UV-dose varies by approximately 4 % per degrees of latitude.

It is quite normal that the ozone layer changes slightly from one year to another. Consequently, the effective UV-dose would exhibit a similar, but opposite variation. An example is given in Fig. 3 which shows the ozone data as well as the annual effective UV-doses for Oslo, Norway on 60° N for the period 1978 to 1988. The ozone data are divided in two groups; *summer values* which include the four months May to August and *winter values* (the four months from December to March). It appears that the low

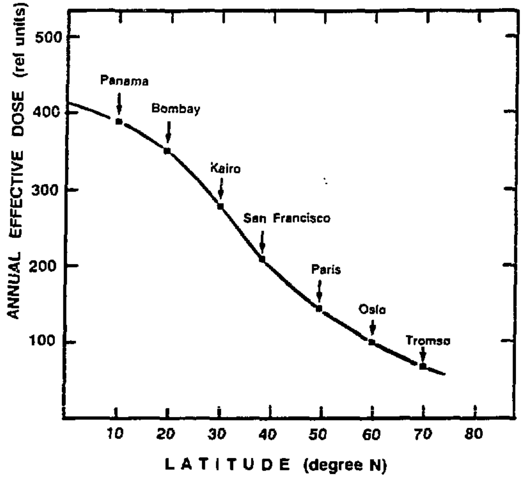

Figure 2: *The annual effective UV-dose as a function of the geographical latitude on the Northern Hemisphere. The curve refers to sea-level elevation. In this calculation the zonal averages of the ozone layer, throughout the year, have been used. The latitude position for some different places are indicated. The dose for 60° N is set equal to 100.*

ozone values in 1983 and 1986 yield effective UV-doses above normal by 2 to 4 percent. The high ozone values in 1982 and 1987 resulted in a similar reduction.

The data in Fig.3 (lower part) demonstrate the close correlation between the summer values of ozone and the annual UV-doses. Thus, the deviations from normal, given in percent, are equal and opposite. The winter values of ozone, which exhibit a larger annual variation, have a negligible effect on the UV-dose at high latitudes. An ozone depletion during the winter months would therefore have a minor effect on the annual effective UV-dose (see Table 1 below).

No particular trend in the ozone values is apparent from Fig. 3 and consequently no particular trend can be expected for the calculated UV-doses.

Ozone Layer Depletion

Based on the procedure used in this work it is possible to calculate effective UV-doses for a number of different ozone layer conditions. In the first place, we assume that the ozone layer is reduced by a fixed amount (a fixed

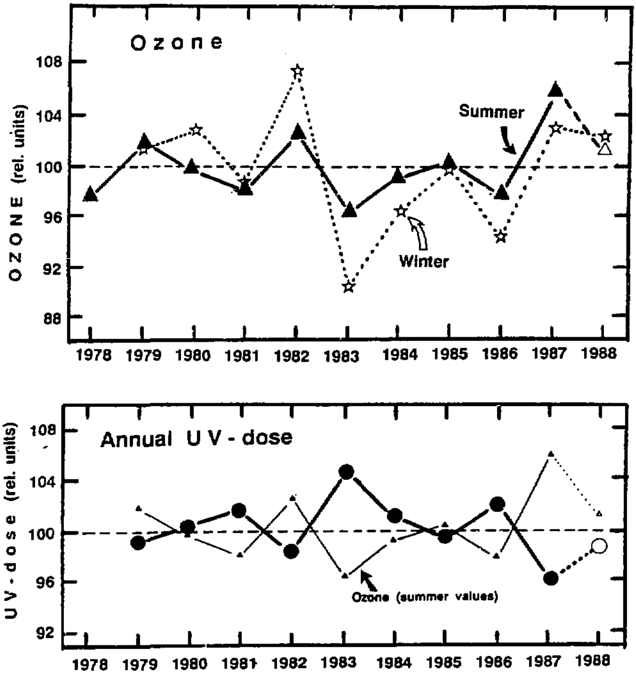

Figure 3: *Ozone measurements (upper part) and UV-dose calculations for the period 1978 to 1988. The data are valid for Oslo, Norway on 60° N. The ozone measurements are divided into summer values (average of the four months May to August) and winter values (average of the four months December to March). The ten year averages are set equal to 100 (dashed horizontal lines). The UV-dose calculations, which are based on the ozone values throughout the full year, are strongly correlated to the summer values of the ozone layer. For this comparison the summer values of ozone are repeated in the lower part. The ozone measurements up to August 1988 are included. Consequently, both the 1988 summer value of ozone as well as the UV-dose for this year are preliminary (marked by open symbols).*

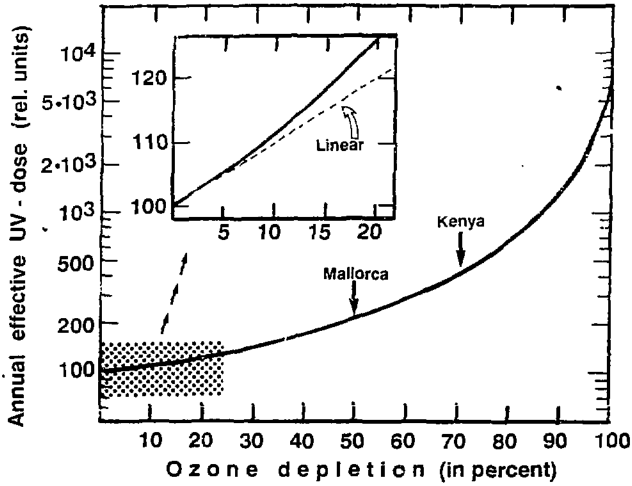

Figure 4: *The annual effective UV-dose at 60° N as a function of the ozone depletion (logarithmic scale). The annual UV-dose, with normal ozone conditions throughout the year, is set equal to 100. The inset exhibits the dotted area with the dose axis enlarged and given on a linear scale. The annual UV- dose for a latitude of 40° N (Mediterranean countries, California) and countries along the Equator, with normal ozone conditions, are indicated by Mallorca and Kenya respectively.*

percentage reduction from the normal value) throughout the year. The results for 60° N are given in Fig. 4.

It appears that for small depletions of the ozone layer (less than 5 % throughout the year) the annual UV-dose increases with an amplification factor close to 1.0 (the dashed line on the inset in Fig. 4). This amplification factor, which is valid for 60° N, increases slightly with decreasing latitudes. A similar amplification factor for the doserate depends largely on the solar zenith angle.

For larger ozone depletions the increase in annual UV-dose is larger. Thus, a 10 percent depletion yields an 11.7 percent larger UV-dose and a 20 % depletion increases the dose by 25.7 %. These values are smaller than those previously calculated by Cutchis (1974). This discrepancy is due to several factors and different procedures for dose calculations, but a significant cause is the action spectrum used for calculating the effective UV-dose. The action spectrum used in the present investigation extends to 400 nm whereas in previous calculations mainly the region 290 to 330 nm has been considered. This difference is important when ozone depletions are evaluated since ozone has a negligible absorption in the UVA region.

The annual UV-dose obtained for a latitude of 40° N and for the countries along the Equator, with normal ozone conditions, are indicated in Fig. 4 by Mallorca and Kenya respectively. It appears that a depletion of the ozone layer over Scandinavia of 50 % (which is far more than all prognoses from atmospheric models) would give these countries an effective UV- dose similar to that normally obtained in California or in the Mediterranean countries.

The data in Fig. 4 indicate (at least in the opinion of the present authors) that depletions of the ozone layer up to about 20 % would have a rather small effect on the life on earth. For ozone depletions of more than 70 to 80 % the effective UV-dose would increase rapidly, mainly due to the fact that radiation with wavelenghts below 295 nm become effective.

The Ozone Hole

The socalled "ozone hole" in Antarctica is a transient springtime depletion of the ozone layer which is connected to the polar vortex. The ozone reduction is probably due to (at least in part) the release of trace gases such as the CFCs. If we assume a similar depletion over Scandinavia (for example; if we moved the ozone hole) the annual effective UV-dose would increase by approximately 22 percent (22.5 % with an evenly distributed depletion and 21.9 % if the whole reduction is concentrated to a region with an elevation between 14 and 24 km in the atmosphere). In this particular calculation we used the ozone values and deviations from normal as those obtained for the Japanese station Syowa on 69° S in 1987 (the ozone values are shifted in time by 6 months to apply for the Northern Hemisphere) (Meshida 1988). It is of interest to note that one would attain a similar increase in the annual UV-dose by moving approximately 5° to 6° towards lower latitudes; for example from Oslo to Northern Germany.

The recent NASA-report (1988), which covered the period from 1969 to 1986, concluded that there was a small negative trend in the ozone values also for the Northern Hemisphere. The extent of the reduction within the period is given for three different latitude regions in Table 1.

The present ozone data for 60° N (Oslo), presented in Fig. 3, are in agreement with the NASA-report as far as the results up to 1986 are concerned. However, if the results up to 1988 are included we arrived at the conclusion that there seems to be no particular trend for the ozone values over Scandinavia (the last ten years).

If we assume an ozone reduction similar to that given in the NASA-report the annual UV-dose for the Northern Hemisphere has increased as given in Table 1.

Table 1. Changes in the ozone layer in the period 1969 to 1986 as reported by NASA and the resulting changes in the calculated effective UV-doses [a].

Period for the ozone changes	Region 53° - 64° N	Region 40° - 52° N	Region 30° - 39° N
Annual average	-2.3 ± 0.7	-3.0 ± 0.8	-1.7 ± 0.7
Winter values	-6.2 ± 1.5	-4.7 ± 1.5	-2.3 ± 1.3
Summer values	$+0.4 \pm 0.8$	-2.1 ± 0.7	-1.9 ± 0.8
Annual UV-dose	+ 0.5 %	+ 3.1 %	+ 2.0 %

[a]. The deviations from normal values (which are the zonal averages) are given in percent. Winter values are the average of the months December to March and summer values are the average of May to August. The annual UV-doses are calculated according to equation (2) with the ozone reductions included.

Surprisingly, the region 53° to 64° N should have experienced the smallest increase in UV-dose (only 0.5 %) in spite of the rather large reduction in the ozone winter values (−6.2 %) which resulted in a reduction of the annual average of 2.3 %. This supports the previous conclusion that a depletion of the winter values is of minor importance.

The increase in the calculated annual dose is small for all regions and corresponds to a southward move of less than 1 degree of latitude (111 km). Furthermore, the NASA-report indicates that the mid-latitude region should have experienced the largest increase in UV-radiation (Table 1).

Even though the change in the calculated effective annual dose is small in Table 1, it is **positive** for all latitudes. In this connection it is of great interest to note that in a recent publication Scotto et. al. (1988) reported a small **negative** trend in the measured UVB-doses (the wavelength region 290 to 330 nm) for 8 different stations in the United States in the period 1974 to 1985 (within the period covered by the NASA-report). The stations covered a latitude region from Tallahassee, Florida (30.4° N) to Bismarck, North Dakota (46.8° N). Even though, the measured UVB-doses are by definition different from the effective doses calculated in this work, it is of interest to note that the two stations mentioned (which have approximately the same elevation) according to Fig. 2 should yield a difference in the annual effective UV-dose of about 65 %. In good agreement with this Scotto et. al. (1988) measured a UVB difference of roughly 60 %.

The negative trend for the observed annual UVB-doses is opposite to that expected from the NASA-report. These conflicting data suggest that other factors in the troposhere also are involved.

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