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Ozone depletion and skin cancer incidence: a source risk approach

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Abstract

The atmospheric ozone layer serves as a protective filter against (part of) the harmful ultraviolet (UV) radiation from the sun. The depletion of the ozone layer, which was observed on a global scale over the past decades, is most probably caused by the global emission of halocarbons, and leads to an increase in UV at groundlevel, and thus, to increases in UV-related risks, like skin cancer incidence. Using satellite data on ozone depletion, a location specific estimate of changes in UV-levels is made for Europe. A source-risk model is used to illustrate effects of countermeasures on future skin cancer risks. Geographical differences and uncertainties are indicated. © 1998 Elsevier Science B.V. All rights reserved.

Keywords: Ozone depletion; Ultraviolet; Skin cancer; Risk assessment; Source-effect chain

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1. Introduction

An increase in ultraviolet (UV) at groundlevel could lead to a variety of adverse effects on aquatic and terrestrial ecosystems, food chains, and human health. Among the adverse effects on human health are increases in skin cancer incidence, cataracts, and possibly an impairment of the immune system. Questions are being raised regarding the extent of the risks involved and the future developments in relation to countermeasures. A collaboration between atmospheric scientists and bio-physicists from the Netherlands (RIVM, Utrecht University) and the USA (NOAA) has lead to a new method, for

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estimating future skin cancer risks in relation to emission scenarios for ozone depleting substances [1]. The method is based on an improved integrated source-risk model, which was previously developed at RIVM [2]. The improved model is used to evaluate excess skin cancer risks caused by ozone depletion in relation to various halocarbon emission scenarios. Geographical differences in UV-changes and associated risk are indicated by means of maps for Europe, and by comparing excess risks in the USA and NW-Europe.

2. Policy agreements

The Vienna Convention in 1985 was the starting point for international policy agreements on the reduction of halocarbon emissions, and provided a framework for the restrictive protocols that came into action later on. The Montreal Protocol in 1987 provided the first restrictive countermeasures, in which the production of the five major ozone depleting substances is restricted to 50% of the 1986 production levels by the year 2000. In view of the compelling evidence that ozone depletion was actually occurring, the restrictions were sharpened in two subsequent Amendments: the London Amendments, which were agreed upon in 1990, and the Copenhagen Amendments in 1992. The London Amendments aimed at a complete phase out of the primary ozone depleting substances at the year 2000, and the Copenhagen Amendments forwarded the complete phase out to the year 1996. Developing countries were allowed longer periods for phasing out the ozone depleting substances. In addition to the restrictions for the primary ozone depleting substances, also, restrictions were put on other ozone depleting substances. Five scenarios are evaluated: no restrictions on halocarbon production (NR), the Montreal Protocol (MP), the Copenhagen Amendments (CA), and two variations on the latter: a more restrictive scenario (CA +) not allowing longer phase out period for developing countries, and a less restrictive scenario (CA −) where 30% of the developing countries do not comply with the restrictions. For the latter scenario, it is assumed that emission levels in 2025 are at 23% of the total 1990 emission, in line with Pepper et al. [3].

3. Methodology: the UV-chain model [1]

The UV-chainmodel integrates dynamic aspects of the full source-risk chain. Starting with the production and emission of ozone depleting substances, the consequences for the ozone layer, subsequent changes in UV-irradiance and changes in skin cancer incidence are evaluated [1]. The combination of predictions for changes in atmospheric ozone, and biologically effective UV with dynamic models for skin cancer induction allows full scenario studies. We investigated the consequences of ozone depletion on future skin cancer risks in relation to the five scenarios, assuming no changes in behaviour and skin sensitivity, nor in cloud and aerosol load of the atmosphere. Furthermore, calculations are based on the present age distribution of the populations. We evaluated the three major skin cancer types: Basal Cell Carcinoma (BCC), the most frequent but least aggressive, squamous cell carcinoma (SCC) and cutaneous Malignant Melanoma (CMM), the least frequent but most aggressive. Present skin cancer incidence is estimated to be around 1100 cases/million/year in NW-Europe, and 2000 cases/million in the USA [1].

4. Modelled processes

Emitted halocarbons are transported to the stratosphere, where photochemical breakdown releases active chlorine and bromine atoms which catalize ozone destruction. An effective chlorine loading was calculated using the method developed at NOAA [1,4]. The evaluation of ozone measurements suggests that downward trends started around 1975–1980, when chlorine levels were already elevated. Therefore, we assume that ozone depletion started after a threshold in effective chlorine loading was reached. Above the threshold, a linear relation between chlorine loading and relative decreases in ozone columns is applied, and at very high chlorine levels, ozone saturation of ozone depletion is inferred (for details see Ref. [1]). We calculated the solar UV spectrum at ground level. The carcinogenic UV-dose is ascertained by weighing of the ambient UV spectrum according to the carcinogenic effectiveness [5]. The last chain in the model consists of a dose-time response model for skin cancer induction developed in close collaboration between Utrecht University and RIVM. The dose-time response models are derived from animal studies, but parameters are calibrated on the basis of epidemiological studies at different latitudes [1]. Differences in the timing of UV-driven processes (early or later stages) are incorporated into the present modelling [1].

5. Geographic differences in UV-changes and skin cancer risks

Ozone measurements from the Nimbus 7 TOMS instrument (version 7 data) [6], are used in combination with a UV-transfer model to estimate location dependent changes in the effective UV at ground level [7] over the period 1980–1991 (see Fig. 1). Fig. 1 shows the relative changes in the UV-level over Europe. The increases are largest in NW-Europe: around 8%. If such increases were to be maintained over a life time, the excess skin cancer risk is provided in Fig. 2. Due to the non-linearity in the dose-effect relationship, and the higher background UV-levels in southern Europe, the highest excess risks are expected in southern Europe, and in high mountains. It is not likely that the ozone and UV levels will remain stable, and therefore, we investigate changes over time in relation to various emission scenarios in Section 6.

6. Scenario study for effective UV and skin cancer risks

Fig. 3 shows the relative increase in the yearly effective UV dose at 52° north latitude in the Netherlands, as found using the UV-chain model for the five scenarios. The points

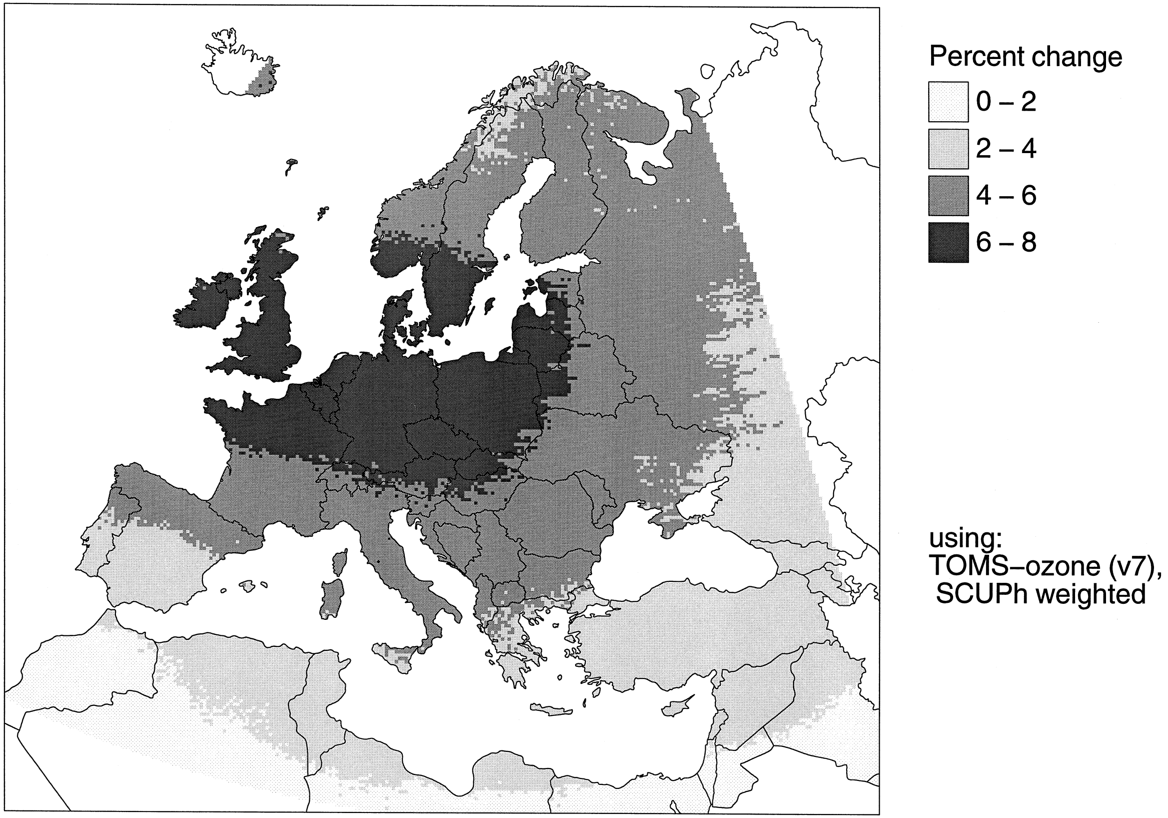

Fig. 1. The relative increase in effective UV-doses related to ozone changes observed from 1980 to 1991. The UV-doses are based on 3-year averages around the year indicated.

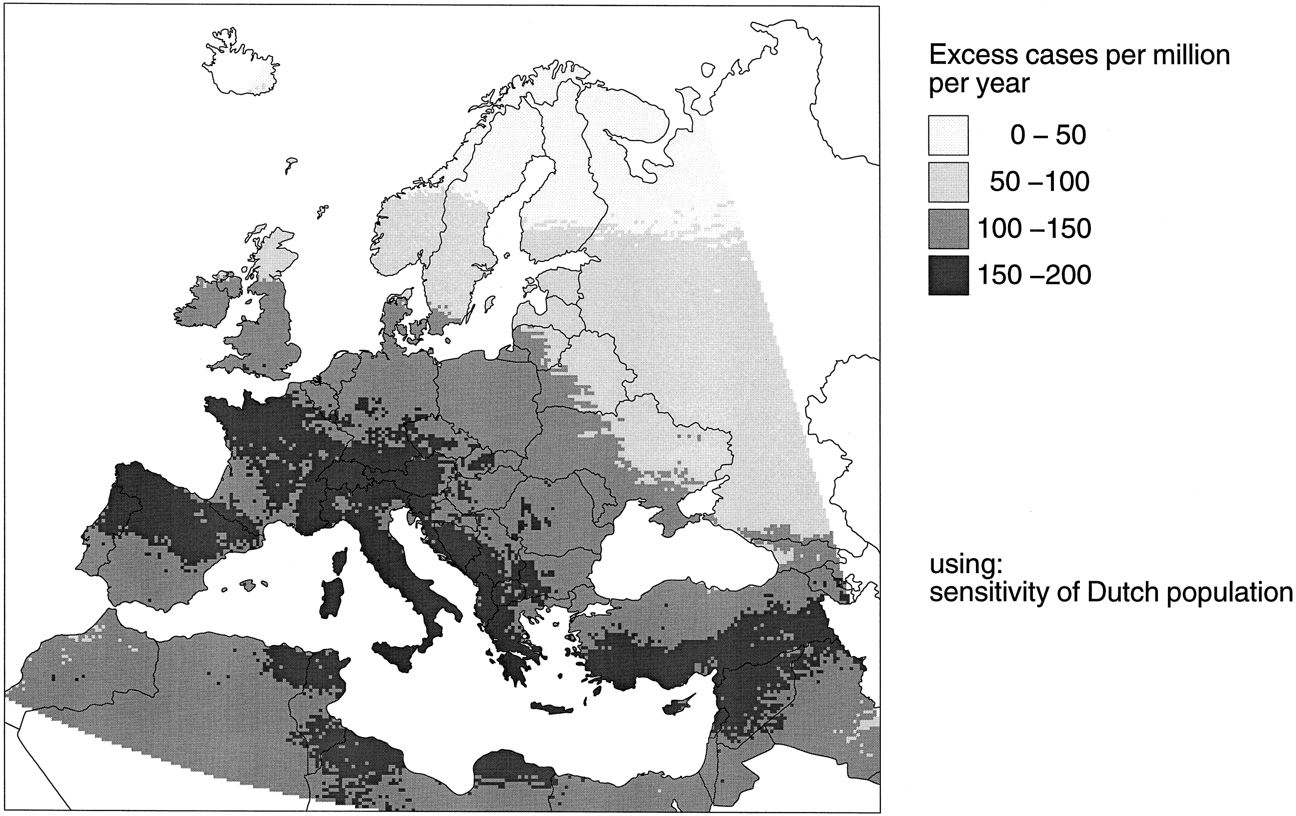

Fig. 2. Location dependent excess skin cancer risks, expressed as excess cases/million/year. The excess risks shown are for a population with the sensitivity of the Dutch population, and assuming that the increased UV-levels shown in Fig. 1 are maintained over a lifetime.

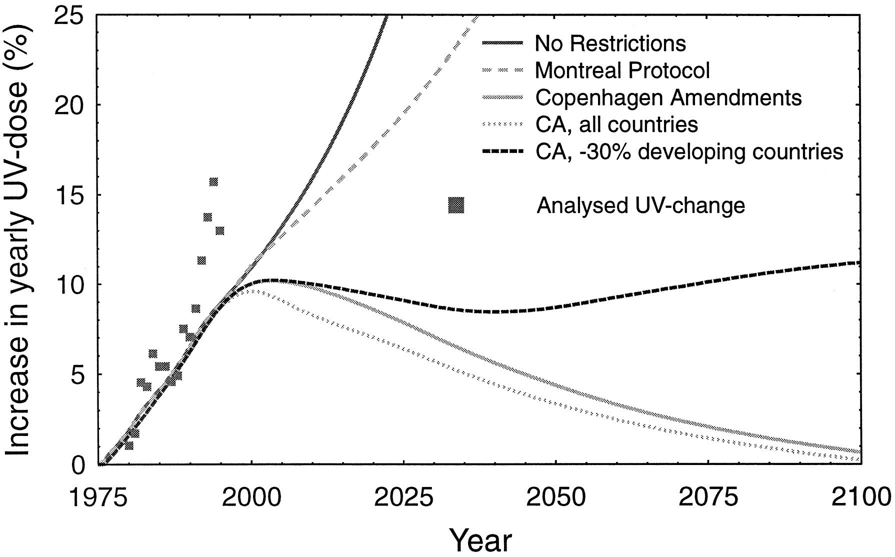

Fig. 3. Relative increase in yearly effective UV-dose received at ground level at 52° north latitude (NW-Europe), for each of the five scenarios. The squares give the 3-year average yearly dose derived from ozone observations.

in Fig. 3 indicate modelled UV-doses based on observed changes in the ozone layer. Each point represents a 3-year running average of the UV-dose. The figure clearly shows that UV-doses in the 1992–1995 period are considerably higher than modelled for the five scenarios. This is possibly due to enhanced chemical breakdown of ozone, caused by the volcanic eruption of Pinatubo in 1991. If we include these recent years in the calibration of the UV-chainmodel, the risks would increase 20–40%. However, it is expected that the enhanced depletion will not continue for a prolonged period. A slow recovery of the ozone layer can only be expected in the CA and CA + scenarios, which show a maximum UV increase of + 10% around the year 2000.

Fig. 4 shows the excess skin cancer risks combining the changes in UV-exposure with the dynamical skin cancer models. Comparison of Figs. 3 and 4 indicate a 60-year delay between the exposure and risk peaks in the CA scenario. Excess risks for the USA are nearly 2 × higher than the risks shown for NW-Europe. Assuming a population of 160 million for NW Europe and 225 million for the USA, the number of excess skin cancer cases that can be avoided by complying with the CA-scenario amounts to more than 500 000 cases/year in NW-Europe and nearly 1.5 million/year in the USA by the end of the next century. Approximately 2% of the cases are fatal. These estimates of excess skin cancer risks are probably conservative, because UV-levels in the 1990–1995 period are underestimated by the model, effects of ageing populations are not included, and trends in behaviour are not included.

Clearly, uncertainties are involved in predicting future skin cancer risks accurately. An uncertainty analysis has shown the statistical significance of the differences between

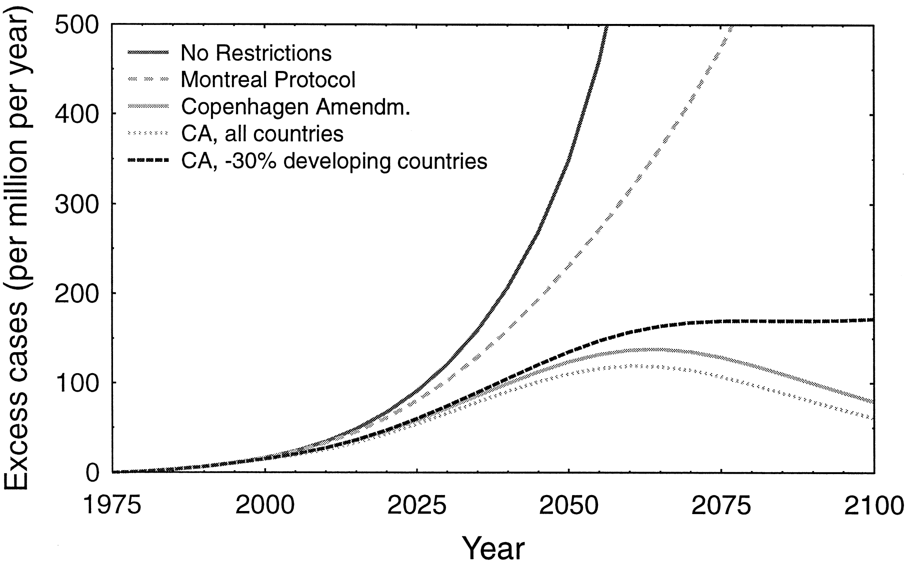

Fig. 4. Excess incidence calculated for the population in NW Europe, incorporating the delay between exposure and the occurrence of tumours. Excess incidences for the USA are nearly double compared to the ones shown for NW Europe.

the three main scenarios (NR, MP and CA) [1]. Even in the CA scenario, the calculated number of excess cases caused by ozone depletion exceeds 33 000/year in the USA around the year 2050 and 14 000/year in NW Europe.

7. Conclusions

The projections presented demonstrate the relevance of the global compliance with the strictest measures agreed upon: the Copenhagen Amendments. UV-levels in NW Europe were surprisingly high in the most recent years and continued ozone and UV-monitoring should establish the success rate of implementing the policy agreements. Comparing risks related to ozone depletion to other environmental risks requires consideration of the global aspects, the burden for future generations and the definition of risk groups, in terms of sensitivity and behaviour. Furthermore, other adverse UV effects and uncertainties in estimates should be considered.

Acknowledgements

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