

AN OVERVIEW OF THE SCIENTIFIC ASPECTS OF OZONE DEPLETION AND THEIR IMPACT ON THE ENVIRONMENT

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ABSTRACT

This paper describes the protective action of stratospheric ozone together with different mechanisms causing ozone depletion. Ozone absorbs UV radiation coming from the Sun. Increased UV radiation due to ozone depletion affects people, terrestrial and aquatic ecosystems, materials as well as air quality. Chlorofluorocarbons, halons and methyl bromide are all significant ozone depleting substances controlled under the Montreal Protocol. Satellite observation systems help to predict future changes to the ozone layer. Based on agreements under the Montreal Protocol, the ozone layer is expected to recover toward the middle of the 21st century.

Keywords: ozone, ozone depletion, UV effects, UV absorption, ozone environmental effects, remote sensing.

INTRODUCTION

In 1974, F.S. Rowland and M. Molina published in "Nature" their ideas on the influence of the chlorofluorocarbon (CFCs) on ozone depletion. These gases are used as propellants in spray cans, as well as a cooling medium in air conditioning systems and refrigerators. As might have been expected, this study was not at all welcomed by the industry. However, when in 1985 Farman and their colleagues of the British Antarctic Survey announced the existence of the ozone hole in the Antarctic, and the extension and depth of this phenomenon was confirmed by measurements taken by the Total Ozone Mapping Spectrometer probe (TOMS) on board the NASA's Tiros-7 satellite, the world knew that this was the beginning of a new and serious problem. Further measures carried out later both from the Earth and from satellites have come to confirm the importance of this "hole" which has already caused a 70% reduction of the Antarctic ozone. With an extension of $27 \times 10^6 \text{ km}^2$, it even affects the southern areas of South America and Australia.

Further measures taken worldwide have proved that ozone depletion is a general problem that, with more or less intensity, affects the whole globe. The original cause seems to be always the same one: the photolysis of compounds of anthropogenic (man-made) origin which, due to their high stability, manage to reach the stratosphere. Here, under the action of UV radiation, Cl and Br are given off, giving rise to cyclic reactions whose result is the ozone depletion and whose basic equations are presented below. The UV radiation increase thus created affects all living beings and all ecosystems: terrestrial and aquatic. It even affects micro-organisms, phytoplankton, inert materials and the quality of the air we breathe. After a brief analysis of these effects, I discuss future changes to the ozone layer in the light of the current observations and agreements to reduce ozone depleting substances under the Montreal Protocol.

In 1995, Molina and Rowland were granted the Nobel Prize for their discovery, which came to corroborate its importance.

THE OZONE PROTECTIVE EFFECTS: UV RADIATION

It is important to point out that the ozone presence in the atmosphere can be beneficial or harmful, depending on how high it is. The tropospheric ozone, which is close to the ground, is harmful both for living beings and materials due to its highly oxidising effects. It represents approximately 10% of the Earth's total ozone. The remaining 90% forms the stratospheric ozone layer, between 20 and 30 km high approximately. It is beneficial because it protects the Earth's surface from the UV radiation coming from the Sun, which has a large energy and is capable of causing damages to living beings and materials.

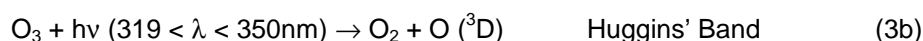
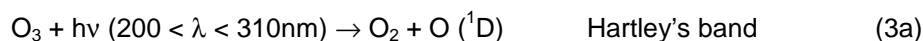
These two "types" of ozone can also be differentiated by their origin. The tropospheric ozone has a photochemical origin and it is produced out of the pollutants which are given off into the atmosphere

from different sources, mainly from road transport and thermal power plants. On the other side, the stratospheric ozone originates in a creation-destruction process.

It is created when the UV radiation with a wavelength $\lambda < 242$ nm reaches the oxygen molecules which are present in the upper stratosphere, given place to the reactions:



Ozone is produced by breaking the oxygen molecule (assisted by highly-energy UV radiation) to form atomic oxygen (O) which then combines with molecular oxygen (O_2), using an external molecule M acting as a catalyst. The balance is kept with a series of the destructive reactions:



"D" means that the resulting atom is in an excited level (Chapman 1930). These reactions show UV radiation absorption by part of the stratospheric ozone in two spectral intervals called Hartley's band and Huggins' band respectively. This mechanism enables the Earth's surface to escape the harmful action of such an energetic radiation, elevating, at the same time, the stratosphere temperature.

OZONE DEPLETION MECHANISMS

The mechanism described in the paragraph above is a balanced process *per se*. It naturally depends on the intensity of the affecting radiation but it balances in a natural way so that the ozone quantity in the stratosphere should remain stable through time. It is higher in the poles and lower in the tropics and it has seasonal changes but locally it should be constant.

However, a series of man-created organic compounds have managed to reach the stratosphere and go over the tropopause, the highest stratosphere border situated approximately 10 km above the Earth. There, under the action of strong UV radiation, they cause "ozone depletion". These chemical compounds are generally called ChloroFluoroCarbons, CFCs. They were invented in 1928 and from 1950 have been produced in great volumes due to their commercial properties. They are commonly used industrially as refrigerants, solvents, different types of foam, aerosol sprays, disinfectants, fast-food containers and pesticides. CFCs are also highly stable which enables them to reach the stratosphere and to live a long time in the turbulent atmosphere. The most important ozone depleting substances are CFC-11, CFC-12, CFC-13 and halons which also contain bromine and are used for firefighting.

In reality, CFC's do not destroy the ozone directly, but they are photolysed in the stratosphere through the UV radiation action, freeing chlorine. A large part of this chlorine ends up as Hydrogen Chloride, HCl, or Chlorine Nitrate, ClONO_2 . These substances are called "reservoir species" and do not react directly with the ozone. Instead, they are decomposed by the UV radiation, giving place, among others, to the atomic Chlorine, Cl, and Chlorine Monoxide, ClO. The final result is that, either through the CFC's direct catalysis or through the decomposition of the reservoir species, free atoms of Cl and ClO appear in the stratosphere which, together with the atomic oxygen, O, coming from the O_2 photolysis (reaction 1), catalyse the ozone destruction through a series of complex and not entirely known mechanisms which could be, nevertheless, represented in a simple manner through the following set of reactions:



Notice that the Cl acts as a catalyst so that at the end of the process it is ready to be re-initiated and therefore does not disappear. This makes it possible for a single atom of Chlorine to destroy millions of ozone atoms before disappearing. The removal mechanism involves the formation of HCl:





Since the HCl is soluble in water, it is eventually eliminated from the atmosphere through precipitation. This is a very interesting reaction since it is one of the means through which the excess of Chlorine in the atmosphere can be cleaned.

Though there is no doubt whatsoever that the Antarctic's ozone hole is due to the CFC's devastating action, this evidence is not so consistent in other latitudes even though there is a general consensus. Leaving natural variations aside, between 1979 and 1991 the total column ozone went down in the mid-latitudes (25-60°) 4.0, 1.8 and 3.8% each decade respectively, for northern mid-latitudes in winter/spring, northern mid-latitudes in summer/ fall and southern mid-latitudes year round. However, from 1991, the decreasing rate has slowed down. The observed total column ozone losses from 1979 to the period 1994-1997 are about 5.4, 2.8 and 5.0% respectively, for the same areas and periods mentioned, which represents a fall in the decreasing rate of 2% approximately.

The destructive effect of the CFC's can be quantified through the "Ozone Depletion Potential", ODP. Typically, it is considered that the CFC-11's ODP is 1.0, and therefore, the action of the remaining ones is taken in relation to the CFC-11. An ODP of 2.0 means that such a compound is twice as 'bad' as the CFC-11. Thus, the ODP of a substance "X" is defined as the relation between the total ozone loss caused by "X" and the total ozone loss caused by the CFC-11. The CFC's have an ODP of around one, whereas the halons, which contain bromine, are much worse. Halon-1211 has an ODP of 3.0, Halon-1301 has an ODP of 10.0 and Halon-2402 has an ODP of 6.0. This is due to the fact that the Bromide does not give rise to reservoir species. Instead, it is directly photolyzed, giving place to similar reactions to those in (5-7).

MB, first listed by the Montreal Protocol as an ODS in 1992, has an ozone depletion potential (ODP) of 0.6 in the Protocol. This was lowered by the Protocol's Science Assessment Panel to 0.4 based on more recent information. However, 0.4 is still considered a significant ODP necessitating the phase out of MB.

ENVIRONMENTAL EFFECTS

The ozone depletion environmental effects are directly derived from the corresponding UV radiation increase which affects as much living beings as materials. The UV radiation is typically divided into three intervals:

UVC: $\lambda < 280 \text{ nm}$ UVB: $280 \text{ nm} < \lambda < 320$ UVA: $\lambda > 320 \text{ nm}$

The UVC is practically entirely absorbed by ozone whereas UVB and UVA, even being partially absorbed, reach the ground. Although UVB, which is more energetic, is supposed to be the worst, recent studies affirm that UVA also affects DNA. Since not all wavelengths have the same effect on living beings due to their different energy, the product of this biological effect by the radiation intensity is known as "erythermal radiation". The increase in this erythermal radiation with respect to the 1970 levels reach 130% in the Antarctic, 22% in the Arctic and 7% and 4% in the Northern Hemisphere winter/spring and summer/fall, respectively. In certain regions of Central Europe increases of over 50% have been punctually measured for ozone reductions of 30%. The relation between the ozone depletion and the increase of the erythermal radiation has been perfectly proved in a large number of places. Such outstanding increases in the radiation intensity affect human health, especially three major organ systems whose cells and tissues are exposed to the Sunlight: the eye, the skin and the immune system. Certain molecules present in these organs called chromophores, are capable of absorbing certain wavelengths, giving rise, through photochemical reactions, to photoproducts. The latter ones cause a biochemical change in the cell, causing either death or permanent alteration. The final result is the whole organism's response which translates into changes in the DNA.

Most skin cancers can be classified into three groups: Basal Cell Carcinomas, BCC, approximately 80%, Squamos Cell Carcinomas, SCC, 16% and Melanomas, 4%. In the USA, more than 90% of skin carcinomas are considered to be caused by UVB. Fortunately, they are not usually fatal when treated on time. Eyes suffer from cataracts and carcinogenesis in the cornea and the choroid. The relation seems to be well established. Besides, these kinds of affections, which used to appear over the age of 60, are now relatively frequent at 40.

Logically, such effects also happen, to a higher or minor extent, in domestic animals. SCC associated to elevated exposures to radiation has been reported in cattle, horses, cats, dogs and other animals.

The terrestrial ecosystems, including plants and microbes, also suffer the effects of UVB radiation increase, though these micro-organisms can also develop some defences. The balance between damage and protection depends on the species and it seems quite clear that it affects through altered patterns of gene activity rather than damage. Such auto-regulative effects become apparent in many different ways, including changes in life cycle timing or in the shape or production of plants. The effects on insects and microbes are also considered to be possible. Analysis of its effect on trees is more difficult, though long natural exposures to UVB are considered to facilitate the attack of insects and pathogens.

Recent studies have proved that UVB and UVA have adverse effects on the growth, photosynthesis, protein and pigment content and reproduction of phytoplankton, thus affecting the food web. The macroalgae and seagrasses also show great sensitivity to UVB. The same can be said about zooplankton and other organisms, such as urchins, corals and amphibians.

Some materials, such as polymers, are also affected in a negative way by UVB radiation and, indirectly, the art heritage also suffers the damages through UVB influence on the air quality. The increase of UVB makes the chemical activity in the troposphere increase, elevating the local concentrations of ozone in highly polluted areas which, considering its oxidising nature, become a highly damaging pollutant not only for materials, but also for health. In this way, a great number of monuments that have remained unharmed over the centuries have recently undergone tremendous damage in just a few years, such is the case of the Aqueduct in Segovia.

THE FUTURE

Since the problem of ozone depletion appeared, extraordinary efforts have been made, both at a political and at a scientific level, to bring a solution. From the scientific point of view, a great number of laboratories have done research trying to work out not just the mechanisms which produce it, its effects and the possible alternatives to the CFC's, but also experimenting and measuring. As it is a global problem, the solution has to be a global one too and the spatial remote sensing was the answer. After flying on board the Tiro-7, the TOMS probe has kept measuring day to day the thickness of the ozone on board the Russian Meteor or the Japanese ADEOS. The SBUV probe has done the same on board the NOAA satellites; the UARS transported the HALOE and CLAES probes to measure the concentrations in the high troposphere of a large number of the compounds involved in the ozone depletion. The recently launched TERRA carries the MOPITT probe on board and the future CHEM, from the EOS programme, will be specifically dedicated to the atmospheric chemistry. The ENVISAT, which will be launched by the European Space Agency this year, carries the GOMOS and the SCHIAMACHY on board in order to measure the ozone and dozens of other different compounds. In conclusion, there is a huge amount of information and talent dedicated to the search for solutions.

The Montreal Protocol, signed in 1987, just two years after the discovery of the ozone hole, seems to be really effective. Examples of its adaptation to the reality are the successive amendments introduced in 1990 in London, 1992 in Copenhagen, 1995 in Vienna, Montreal in 1997 and Beijing in 1999 which have been more and more rigorous and responding with agility to the new knowledge. The ozone layer keeps being depleted, but at a lesser rate. The chlorine concentration is also being reduced, though not the bromine. The concentration of the CFC's substitutes is increasing and, in conclusion, the problem seems to be properly channelled. Despite all that, the consequent increase of UVB radiation is expected to keep affecting the ecosystems. The EPA estimates that a 2% increase in radiation will cause an increase of 2 to 6% of non-melanoma skin cancers and, obviously, these increases will also cause other damage.

Finally, we could ask ourselves: will the ozone layer be regenerated? If the Montreal Protocol is observed, yes, but many of us will probably never see it. The maximum ozone depletion is supposed to be reached during this or the following decade, that is, it will still keep being reduced for a few more years. It must be kept in mind that the cause is the excess of Cl and Br in the stratosphere. What is being done is to slow down or halt the Cl and Br emissions, but we must wait for the Nature to "clean" these substances from the stratosphere. And that has a rhythm that cannot be altered. The new

substances take in between 3 to 6 years to reach the troposphere and it is then when the Cl and Br concentrations would start to weaken. The CFC's time of permanence ranges between 50 and 100 years.

In conclusion, it is a problem whose solution requires patience, but that could be solved by the mid 21st century.

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DOCUMENTING UV RADIATION TO SUPPORT IMPACT STUDIES AND HEALTH PROTECTION FOR CITIZENS

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ABSTRACT

The UV spectral range is divided in three sub-regions consisting of UV-C (200 to 280 nm), UV-B (280-315 nm) and UV-A (315-400 nm). Humans can protect against harmful UV exposure by using UV blocking creams, wearing a hat and sunglasses and avoiding exposure when the radiation is highest. To better quantify UV radiation for its erythemal effects, an action spectrum has been determined that attributes an efficiency factor to each wavelength. To ease the use of the information by the public, WMO has also defined a UV index by mapping the erythemal irradiance on a simple scale ranging from 0 to 10 (in Europe). Solar light intensity is influenced by solar zenith angle, total column ozone, clouds, aerosols, altitude and surface reflectance. Broadband radiometers, multi-channel medium-spectral-resolution instruments and high-resolution spectrometers measure surface UV radiation, often linked into cross-country networks. An increasing number of weather services provide next-day forecasts of UV radiation intensity, usually in the form of a UV index. The forecast can be based on radiative transfer modelling using forecasts of ozone and cloudiness, while others rely more on statistical analysis of long time series of ground UV measurements, combined with the weather forecast. Scientific research on UV radiation and impact studies on the environment and human health contribute toward advice to the public on how to behave safely with respect to UV exposure.

Keywords: UV radiation, sunburns, skin cancer, environment, UV measurements, modelling, UV forecasts.

INTRODUCTION

In terms of energy, the ultraviolet part (wavelengths from 200 nm to 400 nm) of the solar light that reaches the Earth's surface represents only a small fraction of the total but it has an important impact on living organisms. Life as we know it would actually not be possible if the UV radiation was not considerably attenuated by the atmosphere and in particular by absorption in the stratospheric ozone layer.

The UV spectral range is further divided in three sub-regions. UV-C includes the shortest wavelengths from 200 to 280 nm. It is an important factor in the photochemistry of the higher atmosphere but is entirely absorbed by atmospheric gases and does not reach the Earth's surface. Fractions of UV-B (280-315 nm) and UV-A (315-400 nm) do reach the ground and impact biological and chemical processes.

Some of these are related to human health: excessive exposure to UV may induce sunburns, skin ageing, skin cancer or eye diseases e.g. cataract. There is also increased evidence that UV radiation affects many ecosystems. UV is known to kill bacteria, phytoplankton, zooplankton and higher forms of life such as fish or amphibian eggs and larvae. It also negatively affects higher plants. Continued and aggravated ozone depletion would provoke a substantial increase in the UV radiation reaching the Earth and have important health, ecological and economic (e.g. crop yield, halieutic resources) consequences.

Regarding human health issues, it is fortunately easy to protect oneself from excessive UV exposure by using UV blocking creams, wearing a hat and sunglasses and avoiding exposure when the radiation is highest. These protective behaviours can be favoured by providing the citizen with better information on the levels of ambient UV. This necessitates improving our understanding of the factors determining the surface UV, devising techniques to quantify it and developing tools and means to convey the information to the public. An example is how the UV radiation should be quantified for a given effect. The shortest wavelengths are most effective in damaging human skin. UV-B is therefore the most important component but UV-A, because of its higher intensity, does contribute substantially to sunburns.

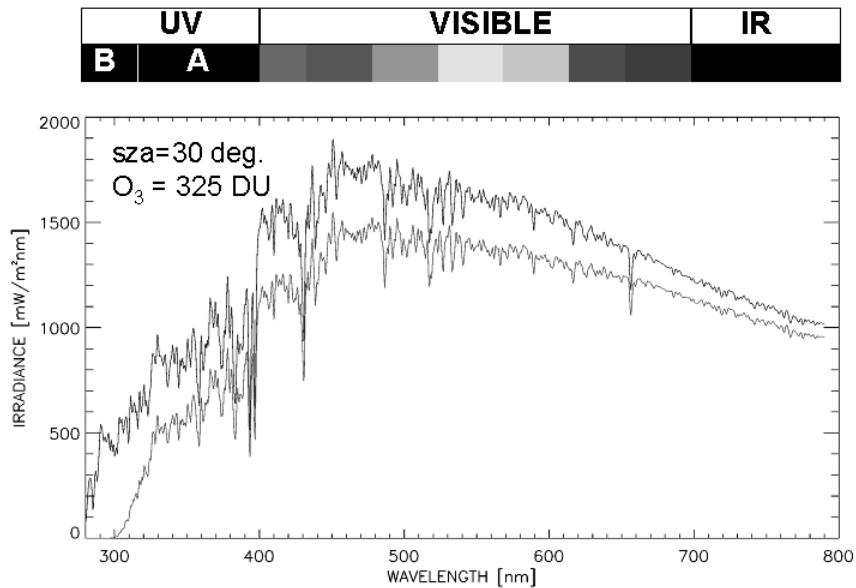


Figure 1: Solar irradiance at the top of the atmosphere (upper curve) and at the Earth's surface under typical conditions (lower curve).

To better quantify UV radiation for its erythemal effects, an action spectrum has been determined that attributes an efficiency factor to each wavelength. The “erythemal irradiance” is then obtained by summing over the whole UV wavelength range the weighted spectral irradiance. The CIE87 action spectrum (Commission Internationale de l’Eclairage – International Commission on Illumination) is widely used for this purpose. There are other action spectra associated with other effects such as skin cancer, DNA damage and effects on plants. The erythemal irradiance is an instantaneous value expressed in W/m^2 .

To ease the use of the information by the public, WMO has also defined a UV index by mapping the erythemal irradiance on a simple scale ranging from 0 to 10 (in Europe). Many European meteorological institutes include this UV index in their weather bulletin or offer the information on their web sites. Data on the surface UV radiation can be obtained either by direct measurements or by radiative transfer modelling.

After a short review of the factors determining the surface UV radiation, the paper briefly reports on these two complementary ways of determining UV radiation.

FACTORS INFLUENCING SURFACE UV RADIATION

Solar zenith angle

The solar light intensity incident on the Earth surface directly depends on the solar zenith angle. This is why it varies with the time in the day (maximum at local solar noon) and with seasons.

Total Column Ozone

Atmospheric ozone is the permanent shield that protects the Earth surface from high levels of UV radiation. It is located throughout the atmosphere but mainly in the stratosphere where 90 to 95% of the total atmospheric ozone is found, hence the term ozone layer. This gas strongly absorbs the short wavelength solar radiation and considerably reduces the UV flux reaching the Earth surface.

With a typical total column value of 325 DU (Dobson Unit), the UV-B irradiance reaching the surface is reduced by a factor 12 with respect to the intensity incident on the top of the atmosphere. UV-C is reduced even more to the point that the amount reaching the surface is negligible while UV-A on the contrary is almost not affected.

Under Antarctic ozone hole conditions (ozone below 200 DU), the surface UV-B intensity can reach twice its “normal” value. Because of different atmospheric conditions (absence of a stable polar vortex, higher temperature) there is not an arctic ozone hole. However, the World Meteorological Organisation estimates that the UV radiation has increased by 3% per decade from 1979 to 1992 in northern mid-latitudes (WMO 1999). Besides the overall depletion resulting from anthropogenic substances, the amount of atmospheric ozone has natural geographical and seasonal variations that contribute to the variability of surface UV radiation. Ozone specifically attenuates the UV part of the solar light while it has almost no influence on visible light. When ozone is low the UV radiation can therefore be high while the perceived luminosity is normal as the human eye is not sensitive to UV radiation.

Clouds

When present, clouds are the major factor reducing the solar light intensity (including the UV) at the Earth surface. This reduction results from light scattering by the water droplets (or ice crystals), which sends back upwards a fraction of the incident light. A thick cloud can attenuate the surface UV intensity by more than 90%. Cloudiness is the most important factor contributing to the year-to-year variability in surface UV radiation and a trend in cloud cover would induce a trend in surface UV radiation.

Aerosols

Aerosols are particles suspended in the atmosphere; they are either of natural (e.g. dust) or anthropogenic origin. Just as the cloud water droplets, they reflect part of the incident solar light. Furthermore, some aerosols (e.g. black smoke) are also strong UV absorbers and large reductions in surface UV have been observed in areas affected by forest fires. In Europe, the atmospheric aerosol load is highest in regions such as the Po valley or the industrial area including Belgium-Netherlands-Luxembourg and the Ruhr, where they reduce surface UV by 5 to 10%.

Altitude

Because the thickness of the atmosphere decreases, the surface light intensity (including UV) increases with altitude. This increase depends on the local atmospheric conditions but is of the order of 15% per km for erythemal (CIE87) radiation.

Surface reflectance

In the UV range, most terrestrial surfaces and water have a very low reflectance (a few percents). The exceptions are sand deserts (~ 15% reflectance) and snow. Pure fresh snow has a reflectance coefficient close to one. In this case the light incident on the surface is backscattered upwards instead of being absorbed. This leads to a substantial increase in UV exposure as experienced for instance during stays in sky resorts.

MEASURING SURFACE UV RADIATION

The basic way of documenting the surface UV radiation is to measure it with ground instruments. Many countries now maintain large networks of UV irradiance instruments, which are particularly well developed in Canada, USA, Japan, New Zealand and Europe. A number of instruments have also been deployed at high southern latitudes in South America and in the Antarctic.

The instruments fall into three main categories: broadband radiometers, multi-channel medium-spectral-resolution instruments and high-resolution spectrometers, in order of complexity and cost.

The broadband radiometers directly estimate the erythemal radiation. They are made of a single detector that receives the light through a filter matching the erythemal action spectrum. At the other end, the high-resolution (0.5-1 nm) spectrometers record the details of the spectral irradiance. The simple instruments allow building denser monitoring networks (low cost and maintenance) but they are subject to drifts in their sensitivity, which are difficult to detect and correct.

The spectral instruments on the other hand constitute the reference in term of accuracy. The detailed spectral information they provide is also crucial to understand the processes determining the surface UV intensity and to improve and validate the radiative transfer models. Important aspects to ensure the consistency and accuracy of the information are instrument inter-comparison, measurement

protocols, quality procedures and archival of the data. The European Commission has strongly supported these activities within its Stratospheric Research Programme. The primary repository of UV data is the World Ozone and Ultraviolet Radiation Data Centre (WOUDC). A European database has also been established at the Finnish Meteorological Institute, with close links to WOUDC.

MAPPING SURFACE UV RADIATION USING SATELLITE DATA

The densest networks of instruments still are and will remain incapable of picturing the full geographical variability of surface UV radiation. Hence the interest of generating maps by radiative transfer modelling and using information on the influencing parameters, some of which is provided by Earth Observation satellites.

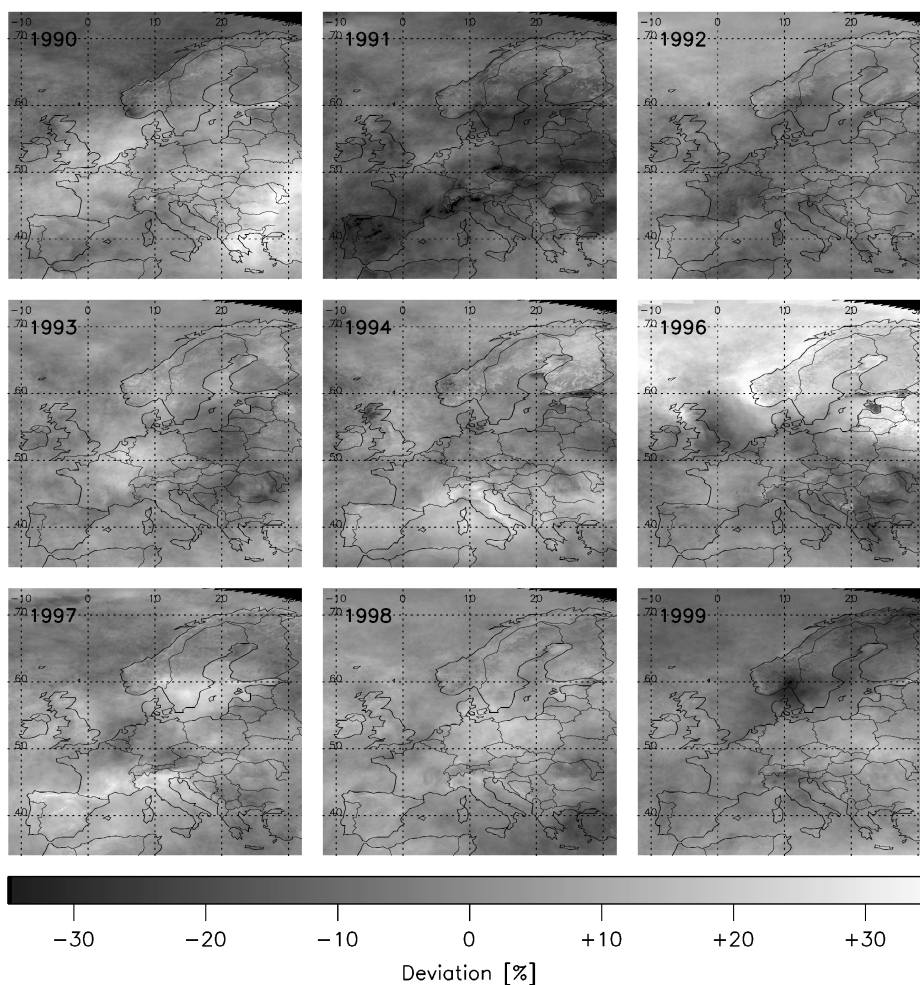


Figure 2: Relative deviation of the monthly averaged erythemal daily dose for March 1990 '91, '92, '93, '94, '96, '97, '98 and '99, with respect to the mean value for the nine years; 1995 is missing because of missing ozone data.

At the global scale, UV climatologies have been generated using data from the TOMS satellite instrument (Total Ozone Monitoring Spectrometer) (Eck *et al.* 1995; Lubin *et al.* 1998; Ziemke *et al.* 2000). Several European groups also have developed UV radiation mapping techniques that are applied on smaller areas but with a higher level of geographical details (Meerkötter *et al.* 1997, Slaper *et al.* 1998).

The European project MAUVE (Mapping UV by Europe, in the framework of the Environment and Climate Programme of DG Research) has largely contributed to this. For instance, the procedure developed at the Joint Research Centre makes use of total column ozone from satellites (TOMS

and/or GOME, the Global Ozone Monitoring Experiment of the European Space Agency), cloud parameters derived from METEOSAT (the European meteorological satellite operated by EUMETSAT) and ground data on the other influencing parameters to generate European maps with a spatial resolution of 0.05 degree (Verdebout 2000).

As archived input data are available, it is possible to document the UV radiation in the past. JRC has undertaken to generate a European climatology covering the period from 1984 to present. A preliminary result is illustrated in Figure 2 which shows the year-to-year variability of the erythemal radiation in March during the nineties. One can see that there are considerable ($\pm 35\%$) differences, which are explained both by variability of ozone and cloudiness. The high values in Greece in 1990, Italy in 1994 and Spain, Southern France and Italy in 1997 correspond to low cloudiness. The high UV in the north in 1996 on the contrary is entirely due to lower than average values of atmospheric ozone. These data are primarily used to support studies of UV radiation environmental impact.

It should be emphasized that these mapping techniques must be validated against the ground reference measurements. Indeed the model output is dependent on the validity of the input data and can only show the effects that have been explicitly taken into account.

NEAR REAL TIME INFORMATION AND FORECASTING

The most important input data to radiative transfer models are available in near-real time: for instance the METEOSAT images are distributed within half-hour of their acquisition and the space agencies have developed fast delivery products of total column ozone. The near-real time UV situation could therefore be estimated and made available to the public.

An increasing number of weather services are actually providing next-day forecasts of UV radiation intensity, usually in the form of the UV index. This is realised in a variety of ways. Some methods are based on radiative transfer modelling using forecasts of the ozone (as predicted by stratospheric circulation models) and of cloudiness (as part of the weather forecast). Others rely more on statistical analysis of long time series of ground UV measurements, combined with the weather forecast. The introduction of the UV index in the weather bulletins is certainly a good way of raising the awareness on the risks of excessive exposure to UV and helps citizens to plan their outdoor activities and to take protective measures.

CONCLUSIONS

There is today a wide range of complementary tools and techniques to document the surface UV radiation, ranging from measurements of various types to mapping by radiative transfer modelling. These means support scientific research on UV radiation and impact studies on the environment and human health but also provide information directly to the public, helping people to behave safely with respect to UV exposure.

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INTERNATIONAL AND EUROPEAN COMMUNITY CONTROLS ON METHYL BROMIDE & THE STATUS OF METHYL BROMIDE USE AND ALTERNATIVES IN THE EUROPEAN COMMUNITY

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ABSTRACT

Methyl bromide (MB) is a significant ozone depleting substance that was added to the Montreal Protocol in 1992. Regulation EC2037/00, adopted on 1 October 2000 in all 15 Member States (MSs) of the European Community (EC), is more stringent than agreements reached by the Parties to the Protocol on MB. Compared to the Protocol, regulations EC3093/94 and EC2037/00 required earlier and greater reductions in MB consumption, a cap on the amount of MB that can be used for quarantine and pre-shipment (QPS), minimum qualification requirements for fumigators, and a ban on the sale of MB in disposable cans. MB consumption is scheduled to be phased out in the EC on 1 January 2005 for the vast majority of its uses. Non-QPS consumption in the EC in 2001 was 7,702 tonnes which was placed on the market mainly in Spain, Italy, France, Belgium, Portugal, Greece and the United Kingdom. QPS consumption in the EC in 2001 was 812 tonnes. Many MSs in the EC have negligible or no further consumption of MB. The Parties to the Protocol are due to review in 2003 the developing country phase out schedule which bans MB consumption in 2015 except for QPS uses and potential critical use exemptions. A survey of MB uses and alternatives being used in MSs in the EC showed that in general alternatives were available but not yet in widespread use. This led to the general conclusion that a much greater effort was needed in technology transfer and awareness raising of alternatives to MB with some continued effort on research and registration of existing chemicals for new uses.

Keywords: methyl bromide, Montreal Protocol, control measures, alternatives, European Community, survey of alternatives

INTRODUCTION

The Montreal Protocol on Substances that Deplete the Ozone Layer (referred to in this paper as 'the Protocol') has 170 signatory Parties and is now widely acclaimed 15 years after its introduction as one of the most successful international environmental treaties. The Protocol establishes the phase out schedules to eliminate the ¹consumption of the most harmful ozone depleting substances (ODSs) including MB(MB) (Anon 2000a). MB, first listed by the Protocol as an ODS in 1992, has an ozone depletion potential (ODP) of ²0.6. This was lowered by the Protocol's Science Assessment Panel (Anon 1999) to 0.4 based on more recent information. However, 0.4 is still considered a significant ODP necessitating the phase out of MB.

The first section in this paper discusses Protocol agreements on MB that affect developed and developing countries, and the EC legislation adopted subsequently that restricts the future use of MB, and the consumption of MB in the EC. The last section discusses the results of a survey of key MSs on MB uses and alternatives in order to determine research priorities, the extent of technology transfer and hence the likelihood of compliance with the Protocol and national legislation on MB.

¹ 'Consumption' is defined as '(Production + Imports) – Exports' which in effect controls the reduced amount of MB that can be placed on the market each year, relative to its consumption in each country in 1991.

² All ODPs are relative to CFC-11 which has an ozone depletion of 1.0. Except for mainly medical uses of CFCs where alternatives have yet to be developed, the vast majority of CFC production was banned in developed countries in 1994.

CONTROLS ON METHYL BROMIDE

Montreal Protocol

Developed countries

The Parties to the Protocol agreed in 1994 to a MB phase-out schedule for countries whose economy is in transition (CEITs) and developed countries consisting of a 25% reduction in consumption on 1 January 1999 relative to 1991 levels, a 50% reduction on 1 January 2001, a 70% reduction on 1 January 2003 and a total phase out of consumption on 1 January 2005 with possible critical use exemptions. Developed countries are permitted to produce 10-15% of their MB 1991 production volume to meet the Basic Domestic Needs (BDN) of developing countries, the precise amount depending on the stage of developing country phase out.

The amount of MB consumed for quarantine and pre-shipment ³(QPS) applications was excluded from control as the Parties in 1994 considered, *inter alia*, MB important for rapid and effective insect disinfestation of a small but highly-valued proportion of food entering national markets. The Parties also wished to avoid any new non-tariff trade barriers as they considered trade was likely to increase in developing countries resulting in greater MB use in these countries in the absence of viable alternatives for QPS treatments.

Developing countries

The Parties to the Protocol typically allow developing countries 10 years longer than developed countries to comply with ODS phase out schedules in recognition of their generally inadequate infrastructural and financial resources. The Parties therefore agreed in 1994 to a MB phase-out schedule for developing countries consisting of a freeze in consumption on 1 January 2002 relative to their average consumption from 1995 to 1998, a 20% reduction on 1 January 2005 and a total phase out of consumption on 1 January 2015 with possible critical use exemptions. The amount of MB consumed in QPS applications was excluded from control.

The Parties also agreed to review at their annual meeting in 2003 the phase out schedule for developing countries with a view to accelerating the phase out schedule in developing countries in the light of progress on the implementation of alternatives. To assist developing countries with the implementation of alternatives, developed countries have to date contributed more than \$50 million from the Protocol's Multi-Lateral Fund. The Protocol's Technology and Economic Assessment Panel (TEAP) is scheduled to produce a report in April 2002 summarising developing country progress on the implementation of alternatives which will provide a useful basis for the Parties' 2003 review of the developing country phase out schedule.

Some developing countries have unofficially accelerated their phase out schedule to avoid further dependency on MB and potential consumer boycotts in developed countries of MB-treated commodities. For example, Morocco has several projects that will introduce alternatives for major crops, and plans to reduce MB imports/consumption from 1,600 tonnes in 1998 to 275 tonnes in 2006 (Miller 2001). Turkey will introduce alternatives for tomato, cucumber, cut flowers and dried fruit, and has made a commitment to reduce MB imports/consumption from 840 tonnes in 1997 to 34 tonnes in 2006.

European Community

³ *The Seventh Meeting of the Parties decided in Dec VII/5 that Quarantine Applications are treatments to prevent the introduction, establishment and/or spread of quarantine pests (including diseases), or to ensure their official control, where 'official control' is that performed by, or authorised by, a national plant, animal, environmental protection or health authority; and 'quarantine pests' are pests of potential importance to the areas endangered thereby and not yet present there, or present but not widely distributed and being officially controlled; The Eleventh Meeting of the Parties decided in Dec. XI/12 that Pre-shipment Applications are those non-quarantine applications applied within 21 days prior to export to meet the official requirements of the importing country or existing official requirements of the exporting country. 'Official requirements' are those which are performed by, or authorised by, a national plant, animal, environmental, health or stored product authority.*

Similar to other Parties to the Protocol, the EC reflected in its own legislation agreements achieved under the Protocol and, moreover, incorporated elements more strict than those in the Protocol where these were feasible. Regulation EC2037/00 on Substances that Deplete the Ozone Layer entered into force on 1 October 2000 in all fifteen MSs in the European Community (EC) more than two years after the original European Commission draft had been discussed and negotiated by industry, the European Council of Ministers and the European Parliament (Anon 2000b). Unlike a Directive whose parts can be transposed into MS legislation, a Regulation is mandatory and must be implemented in its entirety by each MS from the date of its entry into force.

Articles 3 (production) and 4 (placing on the market) contain the most information pertaining to MB in EC2037/00. In general, EC2037/00 mandates larger percentage reductions in MB consumption in the relevant years for non-QPS uses compared to the Protocol but the same final phase-out date as the Protocol. Importantly, through the implementation of EC2037/00, the EC became the first Party to place a limit on the amount of MB that could be used specifically for QPS purposes. The Commission, in consultation with MSs, must also encourage the development and use of alternatives to MB as soon as possible. An international conference such as this one held in Sevilla that summarises the research and implementation of alternatives to MB is one example of meeting the requirements of this aspect of EC2037/00.

In other articles of the Regulation applicable to MB, Article 16 bans MB placed on the EC market in disposable containers. Article 17 requires MSs to have in place qualification requirements for fumigators and to define the minimum qualification requirements for personnel involved in MB installations and operations. All precautionary measures practicable must be taken to prevent and minimise leakages of MB from fumigation installations and operations in which MB is used. Whenever MB is used in soil fumigation, the use of virtually impermeable films for a sufficient time, or other techniques ensuring at least the same level of environmental protection, shall be mandatory.

Non-QPS consumption

Most non-QPS MB is used for soil disinfestation, with smaller volumes used, for example, in the treatment of flour mills, for disinfestation of durable commodities such as rice and cocoa, and for disinfestation of structures such as insect-infested churches.

Relative to 1991 consumption in the EC, the previous regulation EC3093/94 required a 25% reduction in 1998, one year earlier than required under the Protocol (Anon 1994). EC2037/00 required a 60% reduction on 1 January 2001, 10% more than required under the Protocol. A 75% reduction will be required on 1 January 2003, 5% more than required under the Protocol. No further consumption is permitted after 31 December 2004. Any stocks of MB remaining after this date in the EC could be used only until 31 December 2005 whereas under the Protocol they could be used for a longer period of time.

In the calendar year 2001, the quantity of MB licenced by the Commission to be placed on the EC market for non-QPS purposes was 6,362 metric tonnes. The amount requested to be imported was about 17% below the cap in EC2037/00. Of the 6,362 metric tonnes, more than 92% was imported by three of the six MB importers and sold in Spain, Italy, France, Belgium, Greece, Portugal and the UK. Denmark, Finland, Sweden, The Netherlands and Germany no longer use MB for soil disinfestation.

In order to encourage year-long MB availability in 2001 for non-QPS uses, 95% of the quota for each importer was licensed by the Commission for imports from 1 January, 3.75% from 1 July and the remainder from 1 October. Annual import quotas are based on relative historical, importer market-share and approved annually by the Commission and MSs under Article 18 of EC2037/00. Atofina (F) is the only EC producer and was licensed to produce or import up to 1,370 tonnes of MB for non-QPS uses in 2001.

QPS consumption

EC2037/00 mandated a freeze on the use of MB for QPS from 1 January 2001 based on the three-year average of the amount of MB imported and produced from 1996 to 1998 inclusive.

In an emergency, where unexpected outbreaks of particular pests or diseases so require, the Commission, at the request of the competent authority of a MS, may authorise the temporary use of MB. Such authorisation for 120 days or less and cannot exceed 20 tonnes. Commencing in 2002, MSs must report to the Commission on the quantities of MB authorised for QPS in their territory in the previous year, the purposes for which it was used, and the progress in evaluating and using alternatives for QPS. EC2037/00 aims to ensure that MB consumption for QPS is reduced over time as alternatives are developed.

In 2001, EC2037/00 permitted 487 ODP tonnes, equivalent to 812 metric tonnes, to be placed on the EC market for QPS purposes. Based on a Commission survey in 2001, there are no QPS uses in Denmark, Finland and Sweden; and in Austria relatively small quantities of MB are used for emergency QPS applications.

In order to encourage year-long MB availability in 2001 for QPS uses, 90% of the quota for each importer was licensed by the Commission for imports from 1 January and the remainder allocated from 1 October. Annual import quotas are based on relative historical, importer market-share and approved annually by the Commission and MSs under Article 18 of EC2037/00.

Critical uses

For any use of MB that remains without an alternative on 1 January 2005, and in response to any proposal made by a MS, the European Commission together with MSs must determine annually quantities of MB permitted for critical uses, and the users who may make use of the critical use exemption. The Parties to the Protocol must then approve the EC volume of MB requested for critical uses. In determining critical uses, the Commission and MSs must apply the Protocol criteria contained within *Decision IX/6 'Critical Use Exemptions for Methyl Bromide'* (Anon 2000b) and any other relevant criteria agreed by the Parties. The Production or importation of MB can only be permitted once it has been ascertained that supplies of MB (reclaimed, recycled), or adequate alternatives, are not available from any of the MSs.

EC SURVEY ON THE IMPLEMENTATION OF ALTERNATIVES

A survey was conducted by the European Commission on the use by sector of MB for non-QPS and QPS applications in the MSs where MB is currently consumed, namely Spain, Italy, Greece, France, Belgium, Portugal and the United Kingdom. The Form requested information on the availability of alternatives in the next four years. The Survey Form has not yet been returned by Belgium. The Survey Form received from Greece is pending clarification. The results below were therefore obtained from Survey Forms returned by Spain, France, Italy, Portugal and the United Kingdom.

The survey returned by Spain showed mainly that only 14% of non-QPS uses have no potential alternative to MB in 2000, although more than 86% of non-QPS consumption is expected to have an alternative by the end of 2004. Only 30% of the cut-flower growers were using an alternative in 2000. Spain was uncertain if strawberry nurseries and cut-flower growers would be using alternatives by the end of 2004. There were no reported alternatives for QPS uses.

Preliminary information from France reported reductions in the use of MB to about 750 tonnes for non-QPS uses. The reductions were due to officail reduction schedules, a ban on the use of MB in some crops where bromide residues are of concern such as lettuce, and a growing interest in the use of substrates (Fritsch 2002).

The survey returned by Italy showed that, of the 4,000 tonnes of MB consumed in 2000, only 4% of non-QPS uses did not have potential alternative, although more than 96% of non-QPS consumption is expected to be replaced by an alternative by the end of 2004 or 2005. About 30% of the total end-users were using an alternative in 2000. Italy reported alternatives to MB were being used or were under consideration for QPS uses to control a wide range of pest species.

Portugal reported approximately 220 tonnes of MB consumed for non-QPS uses in 2000, most of it used in the production of strawberries (45%) and cut-flowers (28%). Portugal

expected that 90% of its end-users would be using an alternative to MB by the end of 2005. Portugal reported a 38% decrease in sales of MB in 2000 compared to 1999, and a comparable increase in nematocide sales. Portugal reported 2 tonnes of MB for QPS uses on chestnut and almond exports. Heat treatment was under consideration for chestnuts. A treatment for almonds was not known.

The survey returned by the United Kingdom showed mainly that only 3% of users with a potential alternative were using an alternative to MB in 2000, although more than 90% of users are expected to be using an alternative by the end of 2005. Lack of registration is impeding the use of alternatives for food facilities and flour mills. By the end of 2005, the United Kingdom was uncertain if an alternative would be in place for soil disinfestation for cut flowers.

Belgium's MB consumption is reported to have continually declined since 1991 due to interest in production using substrates and other factors (Pauwels 2002). Consumption for non-QPS uses in 2000 was 102 tonnes and is estimated to be 33 tonnes for 2001, compared to 1991 when consumption was 312 tonnes.

Based on these survey responses, it would seem that further research is needed in some areas but the majority of the effort needs to be on awareness raising of alternatives (see Miller 2002) and technology transfer. Some MSs do not appear to have undertaken an assessment of the quantity of MB used and alternatives that have replaced existing uses of MB making an assessment of future compliance with EC2037/00 on MB control schedules difficult to predict. There is also an urgent requirement for registration of existing chemical materials for new uses to allow their use in the EC as alternatives to MB.

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