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Anticipated Public Health Consequences of Global Climate Change

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Human activities are placing enormous pressures on the biosphere. The introduction of new chemicals and the increasing ambient levels of existing chemicals have resulted in atmospheric degradation. This paper reviews some of the adverse effects of stratospheric ozone depletion and global warming. Because the atmospheric effects of ozone depletion are fairly well characterized, quantitative risk estimates have been developed. However, because the atmospheric effects of global warming are less understood, public health problems that could be intensified by climate change are assessed qualitatively. The interactive effects of these two phenomena are also discussed.

Introduction

Human activities are resulting in phenomena that are changing our world in unprecedented ways. Use of nonconservative land practices in the development of food sources to feed a growing global population has resulted in vast areas of deforestation and desertification. Use of the manufactured chemicals chlorofluorocarbons (CFCs) has resulted in degradation of the stratospheric ozone layer, and there is every indication that this will continue for many years to come, eventually resulting in measurable increases in ultraviolet radiation on the earth's surface. Increasing energy usage and the production of meat and grain to support economic development have resulted in increases in the ambient concentrations of CO_2, methane, nitrous oxide, and CFCs. Such increases will contribute to an increase in mean temperature at the earth's surface and may have serious consequences for climatic conditions across the globe. All of these activities contribute to a changing globe and most if not all will contribute to some extent to changes in the global climate and, by extension, contribute to changes in human health. This presentation, however, focuses principally on the anticipated consequences of stratospheric ozone depletions and global warming resulting from the greenhouse effect.

Stratospheric Ozone Depletion

Background

Ozone (O_3) has conceptually been thought of as existing in two layers in the earth's atmosphere: a stratospheric layer and a tropospheric layer. The trophospheric layer hugs the surface of the earth and is part of the air we breathe. In it, ozone is a noxious pollutant, exposure to which has been associated with lung damage and respiratory problems. In the stratospheric layer, however, ozone acts like a protective shield, preventing much of the sun's ultraviolet radiation (UVR) from reaching the earth. This protection is selective, with shorter wavelengths being absorbed preferentially. Thus, energy in the UV-C wavelengths (200–290 nm) is completely absorbed by the ozone layer, while the UV-B (290–320 nm) is only partially absorbed, and the UV-A (320–400 nm) is not absorbed at all. In addition, UVR varies by time and location due to the length of its path through the ozone layer. Radiation entering over the equator has the shortest pathlength and thus encounters less ozone, so more reaches the surface than radiation hitting the surface at the poles. Figure 1

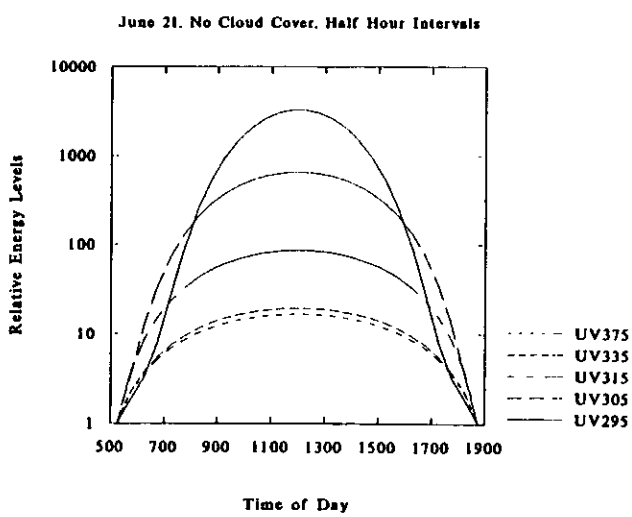

FIGURE 1. Relative changes in radiation for five wavelengths. Estimates taken from the NASA satellite-based model of UV flux developed by Serafino and Frederick (*1*) and adapted by Pitcher and Longstreth (*2*).

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shows model-based estimates of the variation by time of day in UVR by waveband for clear days in Washington, DC. Similar variation is seen by time of day, latitude, and altitude.

Currently, production and release of CFCs have begun to result in a decrease in the concentration of ozone in the stratosphere. With depletion of the stratospheric ozone layer, it has been predicted that more UV-B, particularly in the shorter wavelengths, will reach the earth. The amount of UV-A will remain unchanged, and UV-C is still expected to be completely absorbed. Both UV-B and UV-A are biologically active; however, UV-B, especially the shorter wavelengths, is generally more effective than UV-A for any given effect. The U.S. Environmental Protection Agency (EPA) has been charged with assessing the potential risks associated with stratospheric ozone depletion; as part of that assessment (*3*), the potential impacts on human health of increased UV-B were evaluated. Much of the material presented below has been drawn from that evaluation.

Health Effects of Ozone Depletion

The principal targets of UVR in humans are the skin and the eye; important effects include skin cancer, cataracts, and effects on the immune system. UVR is biologically active chiefly because there are molecules in the skin and the eye that can absorb its energy. Perhaps one of the most important of such molecules, DNA, undergoes a variety of changes upon absorption, including the formation of a number of pyrimidine photoproducts, e.g., cyclobutadiene dimers. Such photoproducts, if not repaired or if misrepaired, are thought to lead to changes in cell function, which may culminate in transformation and neoplasia.

All wavelengths are not equally effective at inducing such effects. Rather, there is a spectrum of energy that for most of the direct effects of UVR cover principally the UV-B region and may in some instances extend into the UV-A region. Each effect has its specific spectrum of effective energy; this has been termed its action spectrum. The exact spectra for effects observed in humans are not known and may never be known. However, spectra have been determined for DNA damage and for carcinogenesis in the mouse; these are presented in Figure 2.

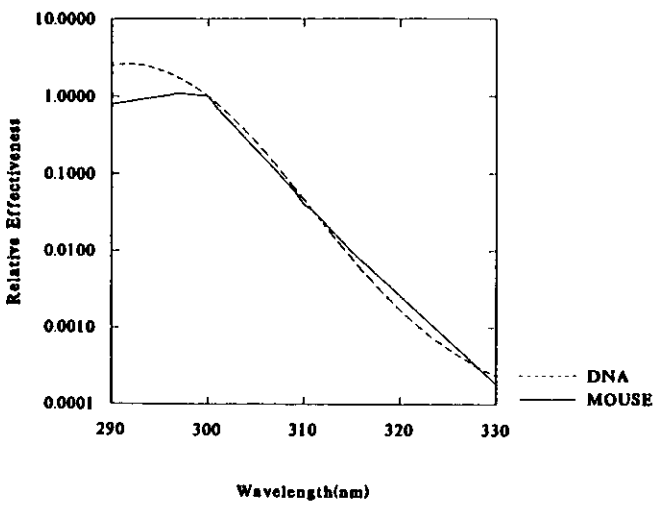

FIGURE 2. Mouse carcinogenesis and DNA action spectra.

Skin Cancer. Exposure to sunlight (and by inference, UVR) has been associated with three forms of skin cancer: basal cell and squamous cell carcinoma (the so-called nonmelanoma skin cancers) and cutaneous melanoma (CM). Basal cell and squamous cell carcinoma (BCC and SCC, respectively) are both malignancies of the epidermal keratinocyte, the major cell of the epidermis. Melanoma occurs via the neoplastic transformation of the pigment-producing cell in the skin, the melanocyte. The linkage between sunlight and nonmelanoma skin cancer (NMSC) is generally thought to be more solid than that for CM. NMSC occurs with greater frequency on the most highly exposed sites, e.g., the hands and face; individuals with fair skin and with the most outdoor exposure, e.g., farmers and fishermen, are at greatest risk. There is also a latitude gradient with individuals living near the equator being at greater risk than those living farther from it. BCC and SCC are much more common but also relatively benign tumors. These two factors have led to a paucity of statistics on these tumors. They are so benign that they are often removed by dermatologists or even general practitioners and not sent for pathologic confirmation, and they are so common that tumor registries would be overwhelmed if reporting became mandatory (which would also require pathologic confirmation.)

The United States has not had a survey to determine incidence on NMSC since 1978 (*4*); the data gathered then indicated that between 400,000 and 500,000 individuals developed NMSC annually. This represented a 15 to 20% increase in incidence when compared to a similar survey performed in 1970–1971 (*4*). Using these data, the U.S. EPA (*3*) estimated that for every 1% decrease in ozone, there would be between a 2 and 3% increase in NMSC. Assuming no controls and growth rates of 1.2 to 5.0% in CFC production, it was estimated that there would be between about 11 and 260 million additional cases of NMSC in individuals alive in 1985 or born through 2074.

However, those estimates may have started with too low a base case. A much more recent study, but of a selected population (those enrolled in a Kaiser-Permanente health plan in Portland, Oregon and Vancouver, Washington) presents a much greater increase (*5*). This study examined pathology records on SCC and CM for the study population spanning the years 1960 to 1986. During that time period, the age-adjusted incidence rates for SCC increased from 9.7 to 29.8 per 100,000 for females and from 41.6 to 106.1 per 100,000 for males. More disquieting, however, was the fact that a comparison of the data from this current study to data from the Seattle population included in the Scotto et al. (*4*) study indicated about a 2-fold discrepancy between the estimates, with the latter study being the lower of the two. There might be several explanations for this discrepancy; two plausible ones are that *a*) the techniques of routine biopsy and pathologic examination of all lesions result in an output that more accurately reflects the true incidence of these lesions than the methodology used in the Scotto et al. (*4*) study, or *b*) the Kaiser-Permanente population, by virtue of being middle class and employed, may be at greater risk, possibly due to more risk-associated behavior, e.g., sunny recreational activities. Either way, the population, or perhaps a specific portion of it, is at greater risk than would be predicted on the basis of earlier studies.

The evidence linking CM to sunlight (and presumably UVR) has traditionally been thought to be less compelling than that cited for NMSC. However, recent evidence, particularly viewed in the context of what was already known, suggests that there are strong reasons to believe that excessive exposure to UV is associated with an increased risk of melanoma. In the past few years, analysis of a number of major case-control studies [reviewed in Longstreth (*6*)] has revealed, almost without exception, an association between melanoma risk and measures that assess increasing intensity of sun exposure. In addition, like NMSC, melanoma affects fair-skinned individuals more than dark-skinned ones and has a latitude gradient, with individuals living nearer the equator being at greater risk than those living farther from it. Unlike NMSC, however, individuals at greatest risk are not those who have the highest sun exposure but rather are indoor workers. The preferred sites also differ with face and hands being major sites for NMSC and the trunk in males and legs and back in females being the major sites for CM.

Eye Disease. When an individual is outdoors, the eye, like the skin of face and hands, is continually exposed to UVR unless protected by glasses or clothing. UVR-induced damage has been documented for the cornea, lens, and retina (*7*). The most common form of damage to the cornea is "snow-blindness," or photokeratitis, the ocular equivalent of a sunburn. Unlike the skin, however, which develops a partial tolerance to the effects of sun through thickening or darkening, the cornea develops no resistance with repeated exposure. This is a common problem among skiers, and it is likely that with ozone depletion enough additional UVR will reach the surface that the risk of this condition will measurably increase.

The most common form of lenticular damage associated with UVR exposure is cataract. There are several forms of cataract; the three most common, cortical, nuclear, and posterior subcapsular cataract, have recently been evaluated in epidemiologic studies for their etiologic relationship to UVR exposure. In these studies, cortical (*8*) and posterior subcapsular cataract (*9*) both showed an association with increasing cumulative UV-B dose or with average annual UV-B dose. Cataract is an increasing problem as the world's population ages (*10*); with increased UV-B due to ozone depletion, even larger impacts are likely.

Immunosuppression. It has been known for some time that UVR has a suppressive effect on the skin immune system. This was originally discovered in experiments done in a nonmelanoma skin cancer model in mice (*11*); it has since been extended to antigens administered in protocols to examine both contact (*12*) and delayed hypersensitivity (*13*) and, very recently, to a variety of infectious diseases when studied in animal systems [reviewed in van der Leun et al. (*15*)]. The immunosuppression that is induced may be either local, i.e., limited to the skin, or systemic; generally, systemic immunosuppression requires a larger total dose to achieve than that required to induce the local effect (*15*). The exact mechanism underlying this immunosuppression is unknown; however, one of the first events observed is loss of activity in a class of antigen-presenting cells in the skin—the Langerhans cells. Shortly after the loss of antigen-presenting activity by Langerhans cells, the subset of lymphocytes responsible for suppression of cell-mediated immunity (T-suppressor cells) appear in the skin. Action spectra for the immunosuppressive effects of UVR demonstrate the greatest activity in the UV-B region (*3*). Of concern *vis-a-vis* ozone depletion, therefore, is the potential impact that additional UV may have on infectious diseases in human populations. The impact could be not only one of perhaps increasing the incidence or severity of various diseases, but it is also possible that vaccination programs designed to protect populations could be ineffective if administered to heavily sun-exposed populations.

Effects Due to Air Pollution. Stratospheric ozone will allow UVR to penetrate deeper into the earth's atmosphere, and there is evidence that tropospheric air quality could be adversely impacted (*16*). To the extent that air pollution increases, individuals with respiratory problems who are sensitive to a variety of pollutants will suffer, potentially resulting in an increase in the number of hospital visits by such people. In addition, there is some evidence that urban smog contributes to respiratory carcinogenesis so that any increase in pollution may eventually result in additional lung cancer incidence (*17*).

Global Warming

Background

The seasonality of disease—flu during the winter, measles in the fall, and sunburn in the summer—is something with which we are all familiar. There is a whole field, biometeorology, devoted to the study of the impact of weather or climate on biologic systems and a rather voluminous literature on the subject (particularly as it relates to human disease) going back to the time of Hippocrates (*18*). With human activities generating ever-increasing concentrations of CO_2 and other radiatively important trace gases, changes in global temperature are likely and with them changes in climatic conditions. How this may affect human health is still somewhat of a speculative question because there are such complexities involved in even assessing the role normal weather plays in human disease, and there are also vast uncertainties in the precise changes in weather anticipated with global warming. The EPA was charged, however, with developing a Report to Congress on the Potential Consequences of Global Climate Change for the U.S., including an evaluation of potential impacts on human health (*19*). Much of the material presented below has been drawn from that evaluation. As with all such assessments, often the analytical exercise of evaluating what may happen can provide important clues to what scientists and policy makers should be following to determine if a risk is real or imagined.

Health Effects of Global Warming

The health effects of global warming are much less easy to identify than those likely to be associated with stratospheric ozone depletion. With ozone depletion there is an easily identified culprit: an increase in UV-B, with fairly well-defined effects. As shown in Figure 3, with global climatic change, the impacts will be secondary and even tertiary, i.e., few of the predicted effects are directly related to the direct impact of heat on a cell or an organ such as would be observed with a burn; they are likely to be the result of what the impacts of heat would be on ecosystems such as forests and farmland.

Heat Stress. Perhaps the easiest adverse effect to predict from global warming is the impact of increased temperatures.

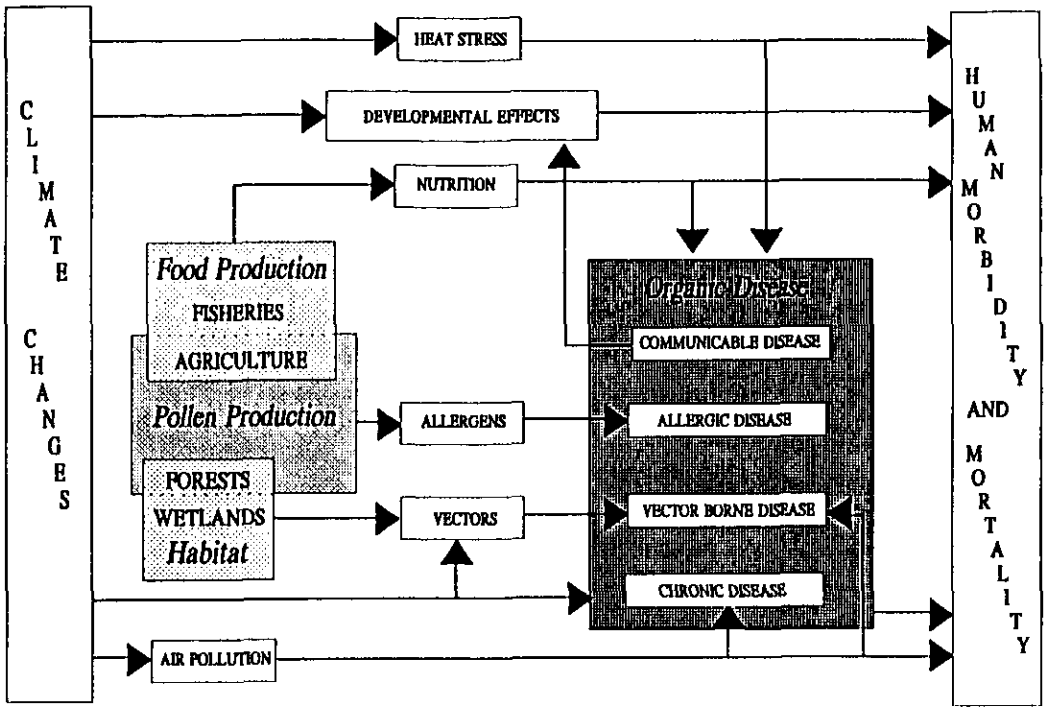

FIGURE 3. Public health impacts of global climatic change.

Heat places stress on the thermoregulatory system, which is intimately tied to the circulatory system. In individuals whose circulatory systems are already compromised by heart, respiratory, or vascular problems, additional stress brought about by increased temperature can be disastrous, resulting in significant increases in morbidity and mortality. In a study performed for the EPA, Kalkstein (*20*) evaluated the potential impact of global warming on temperature-related mortality in 15 cities across the United States. The outcome was highly dependent on the degree of acclimatization predicted. With complete acclimatization, little or no effect was predicted. However, with moderate acclimatization, a net increase in mortality for the 15 cities was predicted, even when taking into account that the number of cold-related deaths would probably drop.

The Kalkstein study (*20*) found that generally, cities in the South did not show summertime heat-related increases in mortality presumably because their populations became acclimatized in some fashion to hot weather. If, with global warming, populations in Northern cities became like those in the South, then full acclimatization will have occurred and little or no impact of global warming is predicted. If populations in Northern cities continue to behave in their current fashion, i.e., do not acclimatize, then a significant increase in heat-related mortality is predicted.

Vector-borne Disease. Potential changes in weather that may occur due to global warming include changes in temperature and rainfall. The most likely scenarios include regions becoming either warmer and wetter or warmer and drier than before, but it is also conceivable that some places will become colder and wetter or dryer at least at particular times of the year. Vector-borne diseases are spread to man from insect and arachnid vectors such as mosquitoes and ticks. The natural history of most Vector-borne diseases is almost always tied to such weather parameters as humidity and temperature either directly or via the impact that these parameters have on forests and wetlands that are critical habitats for such organisms. Thus, it seems entirely plausible that changes in climate may result in changes in the distribution and quantity of vectors and thus may affect such diseases (*21*). It should be noted, however, that modeling the impact of weather on such diseases is a very complex process because these diseases are dependent on having just the right weather, habitat, and intermediate hosts at exactly the required time in their life cycles. Since all of these factors will vary depending on how the weather changes, determining the precise impact of global warming on these diseases requires knowing with a fair degree of precision the regional impacts of a phenomenon that is even now only poorly characterized at a global level.

For the Report to Congress on the Potential Impacts of Global Climate Change (*19*), one study was commissioned that attempted to evaluate the likelihood that global warming would make the United States a more hospitable place for either malaria or Rocky Mountain spotted fever (RMSF)(*22*). The conclusions of that study, which used models for the relationship of malaria or the dog tick (vector for RMSF) to various weather/climate parameters, were that the southern portion of the United States would become no more hospitable than it already is for malaria, and that it seems likely that the habitat for the dog tick would spread north into Canada. It should be noted, however, that in both of these modeling exercises, the parameterizations for habitat and intermediate host availability were not changed when the other parameters were modified to account for global warming. Thus, the conclusions from this exercise have to be accepted with caution.

Respiratory Disease. Individuals with preexisting respiratory disease are likely to be adversely impacted by increased heat

stress as mortality due to respiratory disease increases with elevated temperatures (*23*), presumably due to combined insults of disease and temperature on the circulatory system. Increases in temperature are also likely to have an impact on the degree of air pollution experienced in U.S. cities with high levels of pollutants such as ozone being achieved earlier in the day and maintained longer (*19*). Asthmatics and individuals with other respiratory problems will have greater difficulty as such occurrences become more frequent, and it is conceivable that such episodes could also elevate the frequency of respiratory cancer (*17*).

Allergic Disease. Global warming is likely to have impacts on forests, farmland, and wetlands. To the extent that these latter impacts result in changes in the degree or quality of vegetation, there are likely to be quantitative and/or qualitative changes in the airborne concentration of allergens, e.g., molds and pollens. This in turn could lead to changes in the prevalence or intensity of asthma and hay fever episodes in affected individuals.

Developmental Effects. Impacts of elevated body temperature on fertility (*24*) and on neonatal development (*25*) are well recognized; however, there is very little information in the literature indicating that such an effect could be associated with elevated environmental temperatures. Recently, reports have appeared in the literature indicating a seasonal (summertime) increase in perinatal mortality (*26*) and/or preterm birth (*27*) in two large-center studies. Further investigation of these observations is needed to evaluate whether the observed summertime peak in perinatal mortality or preterm birth is a general one and whether an association can also be demonstrated with elevated temperatures. The United States has a poor record in this area already, and if temperature does play a role in these phenomena, then current efforts to reduce infant mortality need to take such a relationship into consideration.

Impacts Due to Malnutrition and Lack of Water. Increases in global temperature are likely to cause droughts and associated disruptions in agriculture and water supplies. The United States and other highly developed nations probably have the resources and the infrastructure to adjust, with regional impacts being ameliorated by national distribution systems. In the less well-developed nations, it is likely that these effects will result in famines, thereby contributing to malnutrition and increased susceptibility to a variety of infectious diseases. The World Bank has estimated that there are at least 100 million individuals in Africa who do not have enough food (*28*); the additional problems due to global warming can only serve to make such a bad situation worse.

Impacts Due to Crowding. As global temperatures rise, so will the sea level, eventually placing many thousands of hectares of land under water. Much of the world's populations live on coastlines that will be threatened, and as the coastlines disappear, their residents will be crowded into less land area. Such crowding is likely to exacerbate many of the problems already encountered in the megacities housing much of the population in developing nations.

Interactions

Although the potential impacts of stratospheric ozone depletion and global warming have been evaluated as if these were separate or discrete phenomena, there is no question that the impacts associated with them will co-occur. Thus, it is critical to evaluate what if any systems might be jointly impacted. Two such health effect areas come to mind. The first are respiratory effects in that both global warming and stratospheric ozone depletion will result in increases in air pollution. Not only that, but industrialization, as it progresses in the developing nations, will also contribute to air pollution problems. Thus is seems likely in the coming decades that one of the largest public health issues will be respiratory diseases brought about by increased air pollution. This issue has both local and global implications. Local controls will help reduce the industrial emissions, but global controls will be required to reduce the contribution to these problems made by global warming, stratospheric ozone depletion, and acid aerosols.

The second effect that has the potential to be affected both by ozone depletion and global warming is infectious/communicable diseases. As UV-B increases with ozone depletion, it may potentially affect immunity to such diseases at the same time that changes in climate due to global warming may result in the expression of diseases in areas that have never dealt with them before. This could cause a situation where a population has a depressed immunity to a disease and is exposed to it in an area where public health facilities are ill prepared to deal with it.

Conclusions

There is still much that is unknown about the potential health effects of global climate change. The various phenomena that can be said to contribute to the rubric include stratospheric ozone depletion, global warming, acid aerosol formation, desertification, and deforestation. At the current time, these phenomena are being investigated separately, yet the case can and should be made that these things are happening concurrently and there are many instances where interactions are possible as well as likely. Thus, a more global view is required, particularly with regard to the science, but also with regard to policy. These phenomena are not occurring independently, and to analyze them and try to develop responses to them as though they were seems an exercise designed to fall short of the optimum solution. Although it is sometimes helpful to divide a problem into components in order to analyze what contributions are made by the various pieces, at some point the analyst has to reassemble the parts and look for the sum of the effects. This has not yet been done in the public health arena regarding global climate change, and there is very little evidence that it is being done in other important areas such as agriculture and natural resources.

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