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AN ASSESSMENT OF THE RISKS OF STRATOSPHERIC MODIFICATION

Volume 1: EXECUTIVE SUMMARY

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INTRODUCTION

This document summarizes a five volume assessment of the risks of stratospheric modification. Since the early 1970s, scientists have been concerned that human activities could alter the composition of the stratosphere, leading to reductions in the quantity of ozone. If such reductions in ozone levels occurred, public health and welfare would be harmed. Substantial scientific progress has been made since concern about ozone depletion was first raised. This document represents a synopsis of current understanding of how atmospheric composition may change, the effects this change is likely to have on ozone abundance and its vertical distribution, and the impacts of these changes in ozone on skin cancer, cataracts, suppression of the immune system, materials, plants, and aquatic systems. It also examines related changes in climate and the potential impacts of climate change on sea level rise, agriculture, human health, water resources, and forests. Despite significant improvement in our understanding of these issues, substantial uncertainties remain. This risk assessment identifies and discusses these uncertainties and, where possible, estimates quantitatively their potential significance.

This summary volume is organized in four sections:

- Summary findings (see page 2);

- Possible changes in future atmospheric composition (see page 7);

- Implications of changes in atmospheric composition on column ozone abundance and structure, and on global warming (see page 17); and

- Potential human health, environmental and welfare effects from changes in atmospheric ozone and global temperature (see page 27).

Readers desiring greater detail are encouraged to refer to the five volume risk assessment.

SUMMARY FINDINGS

1. Considerable research has taken place since 1974 when the theory linking chlorine from chlorofluorocarbons (CFCs) and depletion of ozone was first developed. While uncertainties remain, the evidence to date continues to support the original theory that CFCs have the potential to decrease stratospheric ozone.

2. Atmospheric measurements show that the chemical composition of the atmosphere -- including gases that affect ozone -- has been changing. Recently measured annual rates of growth in global atmospheric concentrations of trace gases that influence ozone include: CFC-11: 5 percent; CFC-12: 5 percent; CFC-113: 10 percent; carbon tetrachloride: 1 percent; methyl chloroform: 7 percent; nitrous oxide: 0.2 percent; carbon monoxide: 1 to 2 percent; carbon dioxide: 0.5 percent; and methane: 1 percent. More limited measurements of Halon 1211 show recent annual increases of 23% in atmospheric concentrations.

3. CFCs, Halons, methyl chloroform, and carbon tetrachloride release chlorine or bromine into the stratosphere where they act as catalysts to deplete ozone. In contrast, carbon dioxide and methane either add to the total column of ozone or slow the rate of depletion. The effect of increases in nitrous oxide varies depending on the relative level of chlorine.

4. Future changes in emissions of these gases will significantly affect total column ozone. CFCs, methyl chloroform, carbon tetrachloride, and Halons are industrially produced. Emissions of methane, carbon dioxide and nitrous oxide occur from both human activity and the natural biosphere. Because all these gases (with the exception of methane and methyl chloroform) have atmospheric lifetimes of many decades to over a century, emissions today will influence ozone levels for a very long period of time.

5. In order to assess risks, scenarios of atmospheric change were evaluated using models. For CFCs, methyl chloroform, carbon tetrachloride, and Halons, "what if scenarios" were developed based on analyses of the demand for goods using these chemicals (e.g., refrigerators, computers, automobile air conditioners) and the historic relationship between economic activity and the use of these chemicals. To reflect the large uncertainties inherent in these scenarios, particularly with respect to technological innovation and the possibility that industry and consumers will voluntarily limit their future use of these chemicals due to concern about ozone depletion, a wide range of scenarios was examined. The scenarios range from a voluntary 80 percent phase-down in the use of CFCs by 2010 to an average annual growth in use of 5 percent per year from 1985 to 2050. For ozone-modifying gases other than CFCs, scenarios were based on recently measured trends, with uncertainties being evaluated by considering a range of future emissions and concentrations.

6. One- and two-dimensional atmospheric chemistry models were used to assess the potential effects of possible future changes in atmospheric concentrations of ozone-modifying gases on stratospheric ozone. These models attempt to replicate factors that influence the creation and destruction of ozone. While the models replicate many of the characteristics of the atmosphere accurately, they are inconsistent with measured values of other constituents, thus lowering our confidence in their ability to predict future ozone changes accurately.

7. Based on the results from these models, the cause of future changes in ozone will be highly dependent on future emissions of ozone-modifying gases. One-dimensional models project that if the use of CFCs remains constant and other trace gas concentrations continue to grow, total column ozone levels would at first decrease slightly and would subsequently increase. If the use of CFCs continues to grow at past rates and other gases also increase at recent rates, substantial total column ozone depletion would occur by the middle of the next century. If the use of CFCs stays at current levels and the growth in the concentrations of other trace gases decreases over time, depletion will also occur.

8. In all scenarios examined, substantial changes are expected in the vertical distribution of ozone. Ozone decreases are generally expected at higher altitudes in all scenarios in which CFC concentrations increase. Ozone increases are expected at lower altitudes in many scenarios examined due to increased concentrations of carbon dioxide and methane.

9. Two-dimensional (2-D) models provide information on possible changes in ozone by season and by latitude. Results from one 2-D model predict global average depletion could be substantially higher than estimates from a one-dimensional (1-D) model for the same scenario. Moreover, the 2-D model suggests that ozone depletion substantially above the global average would occur at higher latitudes (above 40 degrees), and depletion would be greater in the spring than the annual average. Uncertainties in the representation of the transport of chemical species used in 2-D models introduces uncertainty in the estimate of the magnitude of the latitudinal gradient of ozone depletion, but all 2-D models project a significant gradient.

10. Measurements of ozone levels are another valuable tool for assessing the risks of ozone modification. Based on analysis of data from a global network of ground-based monitoring stations, ozone levels have decreased at mid-latitudes in the upper and lower statosphere and increased in the troposphere. Total column ozone has remained more or less stable. These trends are roughly consistent with current two-dimensional model predictions.

11. Recent evidence indicates that since the late 1970s substantial decreases in ozone have occurred over and near Antarctica during its springtime. These losses have been verified by different measurement techniques, and different theories have been suggested explaining the cause of the

seasonal loss in ozone. Insufficient data exist to state whether chlorine and bromine are responsible for the observed depletion, or whether some other factor is the cause (e.g., dynamics or changes in solar flux that alters NOx). Furthermore, even if man-made chemicals are the cause of the phenomenon, stratospheric conditions surrounding Antarctica are different from the stratospheric conditions for the rest of the would so that it cannot be assumed that similar depletion would occur elsewhere. Models did not predict the Antarctic depletion, however. Consequently, the change in Antarctica does indicate that ozone abundance is more sensitive (to yet unknown factors) than previously believed.

12. Preliminary data from Nimbus-7 suggest a significant decrease in global ozone levels may have occurred during the past several years. These data have not yet been published and the data require additional review and verification. If verified, further analysis would be required to determine if chlorine is responsible for the reported decrease in ozone levels, or whether the decrease reflects short term natural variations.

13. Decreases in total column ozone would increase the penetration of biologically damaging Ultraviolet-B (UV-B) radiation (i.e., 290-320 nanometers) reaching the earth's surface.

14. Exposure to UV-B radiation has been linked by laboratory and epidemiologic studies to squamous and basal cell skin cancers. While uncertainty exists concerning the appropriate action spectrum (i.e., the relative biological effectiveness of different wavelengths of light) and the best measure of exposure, a range of estimates was developed linking possible future ozone depletion with increased incidence of these skin cancers (these cancers are also referred to as nonmelanoma skin cancers).

15. Studies predict that for every 1 percent increase in UV-B radiation (which corresponds to less than a 1 percent decrease in ozone), nonmelanoma skin cancer cases will increase by on the order of 1 to 3 percent. The mortality rate for these forms of cancer has been estimated at 1 percent or less of total cases.

16. The relationship between cutaneous malignant melanoma and UV-B radiation is a complex one. Different histological forms exist, and laboratory experiments have not succeeded in transforming melanocytes with UV-B radiation. However, recent studies suggest that UV-B radiation plays an important role in causing melanoma. Uncertainties in action spectrum, dose measurement, and other factors necessitates the use of a range of dose-response estimates. Considering such uncertainties, recent studies predict that for each one percent change in UV-B, the incidence of melanoma could increase by slightly less than 1 percent.

17. Studies have demonstrated that UV-B radiation can suppress the immune response system in animals and possibly humans. While UV-B induced immune suppression has been linked to chronic reinfection with herpes virus and leishmaniasis, its possible impact on other diseases has not been studied.

18. Increases in exposure to UV-B radiation are likely to increase the incidence of cataracts and could adversely affect the retina.

19. While studies generally show adverse impacts on plants from increased UV-B exposure, difficulties in experimental design, the limited number of species and cultivars tested, and the complex interactions between plants and their environments prevent firm conclusions from being made for purpose of quantifying risks. Field studies on soybeans suggest that yield reductions could occur in some cultivars of soybeans, while evidence from laboratory studies suggest 2 out of 3 cultivars are sensitive to UV-B.

20. Aquatic organisms, particularly phytoplankton, zooplankton, and the larvae stage of many fishes, appear to be susceptible to harm from increased exposure to UV-B radiation because they spend at least part of their time at or near surface waters. However, additional research is needed to better understand the ability of these organisms to mitigate adverse effects and any possible implications of changes in community composition as more susceptible organisms decrease in numbers. Finally, the implications of possible effects on the aquatic food chain requires additional study.

21. Research has only recently been initiated into the effects of UV-B on the formation of tropospheric ozone and the weathering of polymer materials. An initial chamber and model study shows that tropospheric ozone levels could increase, resulting in additional urban areas being in non-compliance with National Air Quality Standards. The increase in UV-B would also produce ozone peaks that would be reached earlier in the same day, exposing larger populations to unhealthy levels. The same study also predicts substantial increase in hydrogen peroxide levels, an acid rain precursor. However, because only one study has been done, the results must be treated with caution. Additional theoretical and empirical work will be needed to verify these projections. It also appears likely that the higher UV-B would cause accelerated weathering of polymers, necessitating polymer reformulation or the use of stabilizers in some products.

22. Changes in climate are likely to accompany trace gas growth that alters ozone. While some of the trace gases discussed above deplete ozone, and others result in higher ozone levels, all are greenhouse gases that contribute to global warming. Based on a range of potential future rates of growth of greenhouse gases, current models estimate that by 2075 equilibruim global temperatures may increase by 2°C to 11.5°C. The National Academy of Sciences has recommended that a range of uncertainty for these types of equilibrium estimates is plus and minus 50 percent.

23. Understanding of the possible health and environmental impacts of climate change is very limited. Studies predict that sea level could rise by 10-20 centimeters by 2025, and by 55 to 190 centimeters by 2075. Such increases could damage wetlands, erode coastlines, and increase damage

from storms. Changes in hydrology, along with warmer temperatures, could affect forests and agriculture. In most situations, inadequate information exists to quantify the risks related to climate change.

24. To perform the computations necessary to evaluate the risks associated with stratospheric modification, an integrating model was developed to evaluate the joint implications of scenarios or estimates for: (1) potential future use of CFCs; (2) ozone change as a consequence of CFC use and emissions; (3) changes in UV-B radiation associated with ozone change; and (4) canges in skin cancer cases and cataracts associated with changes in UV-B radiation. The integrating model did not incorporate many potential impacts of stratospheric modification that could not be quantified.

25. A wide range of scenarios of potential CFC use and trace gas concentration growth was evaluated. Across this range of scenarios, ozone change by 2075 could vary from as high as over 50 percent ozone depletion to increased abundance of ozone of approximately 3 percent. This range of ozone change implies a change in the number of skin cancer cases among people alive today and born through 2075 ranging from an increase of over 200 million to a decrease on the order of 4.5 million. The overwhelming majority (over 95 percent) of the increases and decreases in skin cancer cases estimated for this wide range of scenarios is associated with basal and squamous cell cancers (i.e., nonmelanoma skin cancer). Mortality impacts are estimated to be on the order of 1.5 to 2.0 percent of the changes in total cases, and the estimated impacts are primarily associated with people born in the future. The statistical uncertainty of these estimates is on the order of plus and minus 50 percent. Additional uncertainties exist, some of which cannot be quantified. The greatest single uncertainty about future risks is driven by the rate at which CFC use grows or declines. This uncertainty is reflected in the assessment by examining a wide range of "what if scenarios" of future CFC use.

SECTION I

CHANGES IN ATMOSPHERIC COMPOSITION

The abundance of stratospheric ozone depends upon chemical and physical processes that create and destroy ozone. For over a decade scientists have hypothesized that changes in the concentrations of trace gases in the atmosphere could possibly perturb the processes that control ozone abundance and its distribution at different altitudes. The findings of this section summarize the currently available evidence on how emissions and concentrations of various gases may change over time. A series of what-if scenarios are presented that are used in Section III to explore the implications of a range of possible future emissions and concentrations.

FINDINGS

1. HUMAN ACTIVITIES ARE THE ONLY SOURCE OF EMISSIONS FOR THREE IMPORTANT CLASSES OF POTENTIAL OZONE-DEPLETING CHEMICALS: CHLOROFLUOROCARBONS (CFCs); CHLOROCARBONS (CARBON TETRACHLORIDE AND METHYL CHLOROFORM); AND HALONS.

   1a. Since their development in the 1930s, CFCs have become important chemicals used in a wide range of consumer and industrial goods, including: aerosol spray cans; air conditioning; refrigeration; foam products (e.g., in cushions and insulating foams); solvents (e.g., electronics and dry cleaning); and a variety of miscellaneous uses. (See page ___.)*

   1b. CFC-11 (CCl3F) and CFC-12 (CCl2F2) have dominated the use and emissions of CFCs, accounting for over 80 percent of current CFC production worldwide. Because of increased demand for its use as a solvent, CFC-113 (CCl2FCClF2) has become increasingly important as a potential ozone-depleting chemical. (See page ___.)

2. MEASUREMENTS OF TROPOSPHERIC CONCENTRATIONS OF INDUSTRIALLY PRODUCED POTENTIAL OZONE-DEPLETING GASES SHOW SUBSTANTIAL INCREASES.

   2a. Measurements of current global average concentrations of CFC-11 are 200 parts per trillion volume (pptv), CFC-12 320 pptv, CFC-113 32 pptv, carbon tetrachloride (CCl4 140) pptv, and methyl chloroform (CH3CCL3) 120 pptv.

   2b. Based on measurements from a global monitoring network, worldwide concentrations of chlorine-bearing perturbants (i.e., potential ozone depleters) have been growing annually in recent years at the following rates: CFC-11 and CFC-12 at 5 percent; CFC-22 (CHClF2) at 11 percent; CFC-113 at 10 percent; carbon tetrachloride (CCl4) at 1 percent; and methyl chloroform at 7 percent. (See page ___.)

   2c. Limited measurements show that global tropospheric concentrations of Halon 1211, a bromochlorofluorocarbon containing both chlorine and bromine (which is potentially more effective at depleting ozone) have been growing recently at 23 percent annually. Concentrations have been measured as one pptv. (See page ___.)

   2d. Measurements of tropospheric concentrations of Halon 1301, another brominated compound that is a potential ozone depleter, estimate concentrations as approximately one pptv. No trend estimates have been published. (See page ___.)

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* Page numbers refer to the larger Risk Assessment volumes. They are blank now until final revision of the Risk Assessment Document.

3. <u>ALMOST ALL EMISSIONS OF CFC-11, -12, -113, HALON 1211, AND HALON 1301 PERSIST IN THE TROPOSPHERE WITHOUT CHEMICAL TRANSFORMATION OR PHYSICAL DEPOSITION. AS A RESULT, MOST OF THESE EMISSIONS WILL EVENTUALLY BE TRANSPORTED TO THE STRATOSPHERE.</u>

   3a. Gases which are photochemically inert accumulate in the lower atmosphere. Their emissions are likely to migrate to the stratosphere slowly. Estimates of their atmospheric lifetimes (generally calculated based on the time when 37 percent of the compound still remains in the atmosphere) are the following: CFC-11 is 75 years (+32/-17); CFC-12 is 111 years (+289/-46); CFC-113 is 90 years; CC14 is 50 years; Halon 1211 is 25 years; N20 is 150 years; and Halon 1301 is 110 years. (The range provided is for one standard deviation). (See page __.)

   3b. Because of their long atmospheric lifetimes, the concentrations of these gases are currently far from steady state and will increase over time unless there is a large reduction in future emissions. (See page ______.)

   3c. Because of their long atmospheric lifetimes, these gases will continue to contribute to possible future ozone depletion and climate change (CFCs and other gases affecting ozone are also greenhouse gases) long after they are emitted. Full recovery from any depletion or climate change that takes place will take decades to centuries. (See page ___.)

4. <u>WHILE CFCs USED IN AEROSOLS DECLINED FROM 1974 UNTIL 1984, NONAEROSOL USES OF CFCs HAVE GROWN CONTINUOUSLY AND APPEAR CLOSELY COUPLED TO ECONOMIC GROWTH.</u>

   4a. From 1960 to 1974, the combined production of CFC-11 and CFC-12 from both aerosol and nonaerosol applications grew at an average annual rate of approximately 8.7 percent. Total global CFC-11 and -12 production peaked in 1974 at over 700 million kilograms. (See page ___.)

   4b. From 1976 to 1984, sales of CFC-11 and CFC-12 for aerosol applications declined from 432 million kilograms to 219 million kilograms, an average annual rate of decline of over 8 percent. During the same period, sales for nonaerosol applications grew at from 318 million kilograms to 476 million kilograms, an average annual compounded growth rate of 5 percent. By 1986, total CFC-11 and -12 global production was nearly that in 1974. (See page ___.)

5. <u>STUDIES OF FUTURE PRODUCTION OF CFCs-11 AND -12 PROJECT AN AVERAGE ANNUAL GROWTH RATE OF APPROXIMATELY 1.0 TO 4.0 PERCENT OVER THE NEXT 15 TO 65 YEARS.</u>

   5a. A large number of studies of future global demand for CFCs were conducted by experts from six countries under the auspices of the

United Nations Environment Programme. These studies used a variety of methods for estimating both near- and long-term periods. In general, these studies assumed that: (1) demand for CFCs was driven by economic factors; (2) no additional regulations on CFC use were imposed; and (3) consumers or producers do not voluntarily shift away from CFCs because of concern about ozone depletion. These studies provide a range of growth rates for developing alternative baseline scenarios of future CFC use and emissions. (See page ____.)

5b. In general, these studies projected that CFC aerosol propellant applications would remain constant or decrease further in many portions of the world. (See page ___.)

5c. In the U.S. over the past four decades new uses of CFCs have developed first in refrigeration, then in aerosols, then in foam blowing, and then as solvents. Over this period, the use per capita of CFCs in nonaerosol applications has grown 2 percent for every 1 percent increase in gross national product per capita. This relationship encompasses the development of new products; the expansion and maturation of current markets; and the tendency to use CFCs more efficiently in existing products overtime. (See page __.)

5d. Studies have projected that growth in developed countries for nonaerosol applications is expected to be driven by increased use in foam blowing (primarily for insulation) and as solvents, and by the continued introduction of new uses. The wide range of estimates of future growth reflects the large uncertainties related to population and economic growth, and technological change. (See page ___.)

5e. Studies suggest that future CFC use in developing countries will grow faster (i.e., at a higher rate) than future CFC use in the developed world. Nevertheless, the projected rates for the developing countries are lower than the historical rates that have been experienced in wealthier countries. While these studies were done using aggregate relationships of GNP and CFC use, they made different assumptions about how closely the pattern of CFC use in developing nations would replicate the pattern in developed nations, generally assuming lower use rates. However, evidence from one recently completed study (not completed at the time of the UNEP workshop) indicates that in developing countries the penetration of CFC-using goods may be occurring faster than expected on the basis of the historical relationship in developed nations. If that study is correct, growth in developing nations would be larger than projected in the above-mentioned studies, which generally assumed less penetration in developing nations than had occurred in developed. (See page ___.)

5f. For the three long term studies done to date, the central estimate of the annual rate of growth for CFC-11 and CFC-12 over the next 65 years was about 2.5 percent. This estimate is significantly less than would be expected by extrapolating the historical relationships between GNP and CFC production. Furthermore the scenarios used for quantitative risk assessment assume (arbitrarily) that there is no increase in CFC use after 2050. (See page ___.)

5g. Limited studies on CFC-113 and CFC-22 project that in the absence of regulation or voluntary shifts away from these chemicals, their growth will increase at a faster rate than CFC-11 and -12 as new markets develop and existing ones expand (e.g., use of CFC-113 as a solvent in metal cleaning). (See page ___.)

5h. A range of 0% to 5% annual growth for CFC-11 and -12 was suggested for scenario testing at the UNEP Workshop on demand. This wide range of possible future growth is believed to encompass the major uncertainties regarding the factors that drive CFC growth, including different possible futures for global economic growth, technological change, and the patterns of use in developing countries. An additional uncertainty that needs consideration is the potential voluntary response of industry and consumers to concern about ozone depletion. (See page __.)

6. <u>INDUSTRY AND CONSUMER CONCERN ABOUT POTENTIAL OZONE DEPLETION AND THE GREENHOUSE EFFECT COULD MODERATE DEMAND FOR AND SUPPLY OF CFCs.</u>

6a. Industry trade associations and corporations have announced policies that indicate a concern over the potential for atmospheric change caused by CFCs and other potential ozone-depleting substances. (See page ___.)

6b. Many sectors of industry appear to be voluntarily seeking to reduce CFC use even in the absence of price incentives or regulatory requirements. Moderation of the growth in demand for CFCs may occur without pecuniary or regulatory incentives and could modify economically-based scenarios of future CFC demand. (See page ___.)

6c. Concern about ozone depletion could drive long term changes in technology that moderate the demand for CFCs, further modifying economically-based scenarios of future CFC demand (In the absence of concern about ozone, technolgoical change is as likely to increase CFC use as lower it. However, concern about CFCs may focus investment on chemical and product alternatives, channeling technological development in one direction.) Additionally, consumer preferences for products that do not use CFCs and changes in taste that result from new product introductions that occur in the face of concern about CFCs could also dampen the demand for CFCs. (See page ___.)

6d. To reflect: (1) possible shifts in industrial investment in CFC reducing technologies; (2) consumer reaction against CFC containing products; and (3) voluntary industry reductions of CFC use, a scenario was evaluated in which the use of CFCs phases down to 80 percent of current levels over the next 25 years.

7. <u>THE CHLOROCARBONS (METHYL CHLOROFORM AND CARBON TETRACHLORIDE) ARE USED PRIMARILY AS SOLVENTS AND CHEMICAL INTERMEDIATES. ANALYSIS SUGGESTS LIMITED FUTURE GROWTH FOR THESE CHEMICALS</u>.

    7a. Methyl chloroform is primarily used as a general purpose solvent. Global use in 1980 was estimated at nearly 460 million kilograms. Limited analysis of future demand indicates that it is expected to grow at the rate of growth of economic activity (as measured by GNP). Factors affecting future demand include possible control on other solvents (e.g., perchloroethylene or trichloroethylene) because of concern about carcinogenesis. Alternatively, its use could be influenced if CFC-113 use is restricted. Because methyl chloroform has a substantially shorter atmospheric lifetime than CFC-113, it has relatively less potential for depleting ozone. (See page __.)

    7b. Carbon tetrachloride is primarily used to make CFCs in the U.S. In developing countries it is also sometimes used as a general purpose solvent. In general, future production of carbon tetrachloride is expected to follow the pattern of production of CFCs. Emissions are expected to remain small. (See page ___.)

8. <u>HALONS, ON A PER POUND BASIS, POSE A SUBSTANTIALLY GREATER THREAT TO OZONE DEPLETION THAN DO CFCs. THEY HAVE BEEN USED IN HAND-HELD AND TOTAL-FLOODING FIRE EXTINGUISHERS SINCE THE 1970s. ANNUAL PRODUCTION HAS BEEN LIMITED (APPROXIMATELY 20,000 KILOGRAMS) AND EMISSIONS HAVE BEEN ASSUMED TO BE ONLY A SMALL FRACTION OF PRODUCTION BASED ON THE ASSUMPTION THAT THE HALONS REMAIN INSIDE THE FIRE EXTINGUISHERS. RECENT RESEARCH</u> SUGGESTS <u>THE PROPORTION OF HALONS RELEASED MAY BE SUBSTANTIALLY HIGHER. IN THE U.S., INDUSTRIAL RESPONSE TO CONCERN ABOUT DEPLETION FROM HALONS IS LIKELY TO LEAD TO SOME VOLUNTARY STEPS TO CURTAIL EMISSIONS</u>.

    8a. A single study has projected future demand for Halons. It indicates that near-term demand is growing rapidly and that production may double by the year 2000. In that study, longer-term demand is judged uncertain and may range from an average annual decline of 1 percent from 2000 to 2050 to an annual increase exceeding 5 percent. (See page ___.)

    8b. The expected rate of Halon emissions is very uncertain. The one study assumed most production would remain within fire extinguisher systems as part of a growing Halon "bank." That study has been the basis for scenarios used in this analysis. (See page ___.)

    8c. The historic growth in Halon 1211 emissions (recently measured at over 20% per year) is significantly higher than the rate assumed for future years in the one existing study. (See page ___.)

    8d. Discussions with Halon users indicate that Halon 1301 emissions may be underestimated in the study used for this risk assessment. A recent survey showed that existing systems are undergoing widespread testing and accidental discharge occurs more frequently than assumed in prior studies. (See page ___.)

8e. Production figures in Norway have recently been reported. These estimates are much larger than were assumed in this risk assessment. Uncertainty exists about whether the production in other countries is similarly different than the estimates used in the scenarios in this analysis. (See page ___.)

8f. Additional analysis of Halon emission estimates are necessary to assess more adequately the risks associated with this trace gas. (See page ___.)

9. <u>TROPOSPHERIC CONCENTRATIONS OF OTHER TRACE GASES THAT COULD PERTURB STRATOSPHERIC OZONE ARE ALSO INCREASING. THESE GASES EITHER INCREASE OZONE LEVELS OR COUNTER DEPLETION</u>.

9a. Methane (CH4) adds ozone to the troposphere, counters ozone depletion in the stratosphere, and adds water vapor to the stratosphere. Carbon dioxide (CO2) leads to increased ozone in the stratosphere. Nitrous oxide (N2O) by itself would deplete ozone, but also counters depletion in the face of high chlorine levels. The sources of these gases can be traced, in part, to the biosphere and, in part, to human activity. Considerable uncertainty surrounds future emissions and atmospheric concentrations of these gases. (See page ___.)

9b. Atmospheric measurements show that concentrations of these other trace gases have been growing annually as follows: nitrous oxide (N2O) at approximately 0.2 percent, carbon dioxide (CO2) at approximately 0.5 percent, and methane (CH4) at approximately 1 percent (though, because of limited data, it is unclear whether the increase in CH4 has been a straight line or a compound increase). (See page ___.)

10. <u>FUTURE EMISSIONS AND CONCENTRATIONS OF TRACE GASES WITH AT LEAST SOME BIOGENIC SOURCES ARE DIFFICULT TO PROJECT.</u>

10a. Estimates of the current flux of emissions from different sources is very uncertain for both N2O and CH4. Emissions of CO2 from industrial uses are well understood, but contributions from the biosphere remain uncertain. In particular, there is significant uncertainty regarding the portion attributable to deforestation. (See page ___.)

10b. Future changes in human activities that emit these gases (e.g., acreage of rice paddies for methane) generally have not been analyzed by the scientific community (except for industrially-produced CO2). As a result, estimates of future changes in the concentrations of these trace gases must essentially rely on plausible what-if scenarios. (See page _.)

10c. Factors that determine emission rates from various source types are not well understood and may change over time. For example, the extent to which methane releases from rice paddies depend on cropping practices or will be altered by changes in carbon dioxide (which would alter stomatal resistance and thus gas exchange in plants) has not been adequately studied or determined. (See page ___.)

10d. The biogeochemical cycles that control the fate of CH_4, non-methane hydrocarbons, and CO emissions released into the atmosphere also are not well understood. In addition, these processes are likely to change as the global environment evolves. (See page ______.)

10e. An additional uncertainty about future changes in emissions of N_2O, CH_4 and CO_2 is the extent to which, in response to global warming, governments may take action to limit the rise in concentrations of carbon dioxide, methane, and nitrous oxide. (See page ___.)

10f. Because CH_4 has an estimated atmospheric lifetime of 6 to 11 years, its future concentrations are quite dependent on its emissions within a relatively short period of time. Changes in gases that affect the OH radical, the key determinant of CH_4 lifetime, are also important. CO is the most important of these gases. The one study on future emissions of CO projects a leveling out and then decrease of global emissions from energy sources of this gas. (See page __.)

10g. N_2O has an estimated atmospheric lifetime of approximately 150 years. Consequently, its future atmospheric concentrations are dependent on accumulated emissions over long periods of time. (See page __.)

10h. CO_2 emissions are cycled through the biosphere and oceans. While many uncertainties exist about biogeochemical pathways, carbon cycle modeling is well enough advanced so that in the absence of significant change in these cycles, it is possible to project concentrations for given emission scenarios relatively well. However, two major uncertainties exist: the future biogenic and soil emissions of CO_2 in response to climate change; and future absorption and outgassing of CO_2 by the oceans (which could change radically if deepwater formation is altered by changes in climate). (See page ___.)

11. <u>TO ENCOMPASS THE SUBSTANTIAL UNCERTAINTIES ABOUT EMISSIONS AND THEIR EFFECT ON FUTURE CHANGES IN ATMOSPHERIC COMPOSITION, A WIDE RANGE OF "WHAT IF" SCENARIOS WERE DEVELOPED. THIS RANGE WILL PROVIDE DECISIONMAKERS WITH A PICTURE OF HOW UNCERTAINTIES INFLUENCE THE POSSIBLE RISKS OF STRATOSPHERIC PERTURBATION. THE PRIMARY PURPOSE OF THESE SCENARIOS IS TO PROVIDE DECISIONMAKERS WITH "A FEEL" FOR WHAT COULD HAPPEN IN THE ABSENCE OF REGULATION</u>.

11a. The range of CFC growth rates that are used in Section III of the risk assessment encompasses a phase-down to 80% of current levels (due to technological change or anticipatory responses) to a 5 percent annual growth rate in use through 2050, followed by no growth in use through 2100, for an average annual rate of growth of 2.8 percent from 1985 to 2100. (See page ___.)

11b. Scenarios for methane (CH_4) were derived based on estimates of past growth. However, current data are insufficient to distinguish between a 1 percent linear growth rate (approximately 0.017 ppm per year) and 1 percent compound rate of growth. Thus, each is used in the model projections. Other scenarios are also examined, including:

- 0.01275 ppm per year growth (75 percent of the 0.017 ppm or 1 percent linear growth);
- 0.02125 ppm per year growth (125 percent of the 0.017 ppm or 1 percent linear growth);
- 1 percent compound growth from 1985 to 2010, followed by constant concentrations at 2.23 ppm; and
- 1 percent compound growth from 1985 to 2020, growing to 1.5 percent compound annual growth by 2050 and thereafter.

Scenarios for nitrous oxide (N_2O) growth are also based on measurements of historic changes; scenarios of N_2O assume a 0.20 ± 0.05 percent annual rate of increase. Carbon dioxide (CO_2) scenarios are based on the 25th, 50th, and 75th percentile cases of concentrations presented in the 1983 National Academy of Sciences report, for which the doubling dates for CO_2 concentrations are 2100, 2065, and 2050 respectively.

12. <u>ADDITIONAL RESEARCH IS NEEDED TO REDUCE UNCERTAINTIES ABOUT FUTURE EMISSIONS AND CONCENTRATIONS OF TRACE GASES</u>.

12a. Global measurements of concentrations of Halon 1301 and Halon 1211 are critical to assessing the overall risk of ozone depletion. Omission of consideration of these gases in analyses could underestimate risks. (See page ___.)

12b. Global measurements of CO and CH_4 are critical to assessing the future concentrations of CH_4; current measurements of CO are insufficient for evaluating global burdens and chemistry. Additional research must be done on sources, emission factors, and feedbacks which could affect concentrations of these species. (See page ___.)

12c. Global measurements of methyl chloroform, NO_x, OH radicals, and other chemically active constituents will be needed to assess how changes in tropospheric chemistry could influence the abundance of various species that could alter the composition of the stratosphere. (See page ___.)

12d. Research and production data are needed on Halon 1211, 1301, and CFC-113 and -22. In addition, production data are needed for some regions for CFC-11 and CFC-12. Additional research is also needed to determine the potential for technological change and changes in taste that could reduce future demand or supply of all fully-halogenated and other ozone-depleting compounds. Such research would reduce uncertainty about the magnitudes of future risk. (See page ___.)

12e. Significant improvements in data are needed to describe all phases of key biogeochemical cycles. In particular, potential feedbacks from changes in stratospheric ozone or climate must be better understood and incorporated into existing models. (See page ___.)

SECTION II

POTENTIAL CHANGES IN OZONE AND CLIMATE

MODELS OF THE ATMOSPHERE THAT INCORPORATE CURRENT SCIENTIFIC UNDERSTANDING OF CHEMISTRY AND PHYSICS PROJECT SIGNIFICANT CHANGES IN GLOBAL OZONE (TOTAL COLUMN AND/OR COLUMN ORGANIZATION) AND INCREASES IN GLOBAL TROSPHERIC SURFACE TEMPERATURE IF TRACE GAS CONCENTRATIONS GROW SIGNIFICANTLY. UNCERTAINTIES ABOUT MAGNITUDES REMAIN LARGE.

Models that incorporate current scientific understanding are used as the primary tool to project the potential consequences of future changes in abundances of trace gases. These models can be partly tested by comparing their results with measurements of the atmospheric, historically-observed changes, and in the case of climate with paleoclimatic and extraterrestial environments. While current models accurately represent some aspects of the atmosphere, they fail to replicate other characteristics. This section summarizes the currently available evidence on how changing atmospheric abundance could modify total column ozone, alter column distribution and change global climate.

13. <u>BOTH THEORY AND MODELS OF STRATOSPHERIC PROCESSES PROJECT THAT INCREASES IN CHLORINE AND BROMINE WILL DECREASE OZONE, WHILE INCREASES IN CARBON DIOXIDE AND METHANE WILL INCREASE OZONE OR REDUCE DEPLETION. THE EFFECT OF NITROUS OXIDE ON OZONE DEPENDS ON COMPLEX INTERACTIONS AND IS SCENARIO SPECIFIC. WHILE CONSIDERABLE UNCERTAINTIES EXIST ABOUT RELATIVE RATES OF FUTURE GROWTH, IF CFC USE INCREASES SUBSTANTIALLY ABOVE CURRENT LEVELS, TOTAL COLUMN OZONE DEPLETION IS LIKELY</u>.

13a. Photochemical theory continues to support the conclusion that chlorine, nitrogen, bromine, and hydrogen can catalytically destroy ozone in the stratosphere. (See page ___.)

13b. One-dimensional (1-D) models currently predict a 5-9 percent depletion for the steady state concentrations of chlorine that would result from constant emission of CFCs at 1977 levels (and assuming no change in other gases). While useful for intercomparing models, these values cannot be used to assess the risks of depletion in an atmosphere because other gases affecting ozone levels are, in fact, also changing. (See page ___.)

13c. One-dimensional (1-D) models predict average global column ozone will decrease for a scenario in which CFCs and other trace gases (i.e., CO2, N2O, and CH4) continue to rise at approximately historically-based rates. For a scenario in which the use of CFCs grows at 3 percent annually, these models project a depletion greater than 25 percent by 2075 if the other trace gases continue to grow at rates approximating their recent historical growth. (See page __.)

13d. In contrast, for a scenario in which CFC use remains constant, but other trace gases continue to grow at historic rates, 1-D models indicate that ozone levels would first slightly decrease and then begin to increase over time. (See page ___.)

13e. For the same scenario (i.e., no growth in emissions of depleting substances and growth of other substances at historical rates), several two-dimensional models predict that ozone depletion will occur at higher latitudes (only one of these 2-D model calculations simulating this depletion includes CO2 cooling and none include changes in dynamics that such cooling is likely to cause). 2-D models vary in their projections of latitudanal depletion gradients depending on whether they include the effects of CO2 and how they treat transport and methane. Only a limited number of time-dependent two-dimensional simulations have been undertaken, and two-dimensional model intercomparison has not yet been completed. (See page ___.)

13f. Two-dimensional models (2-D) predict greater average global depletion than one-dimensional models for the same trace gas scenarios. Two-dimensional models also project depletion higher than global averages at latitudes greater than 40°N or S, especially in the spring. Nearer the equator these models predict less than the global average. The latitudinal projections of two-dimensional models are sensitive to the data and method used to parameterize transport. Differences in transport probably account for differences in latitudinal gradient of depletion between different 2-D models. (See page ___.)

14. CURRENT THEORY AND MODELS FAIL TO REPRODUCE ACCURATELY ALL OBSERVATIONAL MEASUREMENTS OF THE ATMOSPHERE AND PROCESSES THAT INFLUENCE STRATOSPHERIC CHANGE.

14a. While reproducing many characteristics of the current atmosphere, current models fail to reproduce some measurements. For example, ozone levels at 40 kilometers are underestimated in current models. Other problems exist in the way these models replicate existing observations. (See page ___.)

14b. While including representations of most atmospheric processes that influence stratospheric composition, current models fail to include all of those processes in a realistic manner. Transport processes in 2-D models, for example, are represented in a simplified manner based on inadequate data and an incomplete understanding of the possible complications of movement in the atmosphere. (See page ___.)

14c. The inability of models to reproduce accurately measurements of the abundance of some species in the current atmosphere lowers our confidence in their ability to predict future changes. Because of these shortcomings, current models could be either over- or underpredicting future depletion. (See page ___.)

15. UNCERTAINTY ANALYSES HAVE BEEN CONDUCTED THAT CONSIDER A RANGE OF POSSIBLE VALUES FOR CERTAIN CHEMICAL AND PHYSICAL INPUTS. THESE ANALYSES INDICATE THAT FOR THESE UNCERTAINTIES, DEPLETION IS LIKELY TO OCCUR IF THE USE OF CFCs GROWS.

15a. Uncertainty analyses conducted with one-dimensional models predict depletion for a variety of CFC levels. These analyses indicate that when model results are screened to eliminate cases in which the modeled atmosphere conflicts with actual observations of the atmosphere, the probability of a depletion is symmetrical around the mean. The possibility that the best estimates of kinetics could change as a result of laboratory measurement is ever present. Such changes could raise or lower estimates of depletion. While not yet accepted by the NASA panel on kinetics, a preliminary study of one such reaction, $ClO + HO2 \longrightarrow O3 + HCl$ would, if accepted, reduce depletion estimates. Similarly, a class of heterogenous reactions which could increase depletion estimates are currently omitted from models. (See page ___.)

15b. Uncertainty analyses using different sets of kinetics and cross sections have not been tested in two-dimensional models. However, different 2-D models have used different approaches for transporting species. This provides a useful test of the sensitivity of model predictions to the uncertainty of the transport parameters. Models with different treatment of transport predict that depletion will increase with distance from the equator, though the magnitude differs between models. (See page __.)

15c. Some uncertainties have not been tested in current models (transport coefficients, for example). In addition, the possibility exists that missing or misrepresented factors or processes (for example, due to global warming) may exist and lead to a greater or lesser change in ozone than indicated by existing uncertainty analyses. (See page ___.)

16. <u>OZONE MONITORING SHOWS CHANGES ROUGHLY CONSISTENT WITH MODEL PREDICTIONS. HOWEVER, SUBSTANTIAL MEASURED SEASONAL REDUCTIONS HAVE OCCURRED IN ANTARCTICA THAT ARE NOT CONSISTENT WITH MODEL PREDICTIONS</u>.

16a. Measurements by Umkehr readings show 3 percent depletion at mid-latitudes in the upper atmosphere, while balloons show 1.3 percent depletion in the lower stratosphere and a 12 percent increase in the lower troposphere. Uncertainty exists about the accuracy of all of these observations. These results, however, are roughly consistent with the expectations generated by one-dimensional and two-dimensional models. The ground-based measurement system is limited at high latitudes and in the southern hemisphere. (See page _.)

16b. Recent data from Nimbus 7 appears to show a decrease in global ozone, especially at both poles. However, the decrease in the Arctic from 1978 to 1984 appears to have occurred only in the last two years of that time series. These data are preliminary and have not yet been thoroughly reviewed. Concern about calibration problems of the satellite makes determination of the magnitude of ozone change difficult. However, the latitudinal variations in ozone change seem to indicate that this phenomenon is occurring and the readings are not just the result of instrument drift. (See page ___.)

16c. If these decreases in global ozone levels are verified, a second issue which must be addressed is whether the changes can be attributed to man-made chemicals. Other possible explanations include natural variations caused by solar cycles or other processes. Until further analysis is performed to determine whether depletion is actually occurring, whether it is long term or cyclical, and whether it can be attributed to man-made chemicals, it is impossible to determine the implications of these results with any certainty. However losses of even some part of the magnitude of the preliminary NIMBUS 7 data are not consistent with current model projections, and would be a cause for concern. (See page ___.)

16d. Measurements in the Antarctic spring show that the gradual depletion that occurred in the mid-1970s over and near Antarctica has given way to a steep non-linear depletion from 1979 to 1985 -- the Antarctic "ozone hole." Not only has the ozone minimum decreased, but the ozone maximum outside Antarctica (between 50°S and 70°S) also appears to be declining. The average annual depletion of all areas south of 60°S has been estimated to be more than 6 percent since the mid-1970s. (See page ___.)

16e. Current models did not predict this seasonal loss of ozone in Antarctica. Several hypotheses have been put forward to explain the loss, including chemical explanations in which the gases are of a man-made source (bromine and chlorine), chemical explanations in which natural sources cause the change (NOx, solar cycle), or an explanation that claims the phenomenon is entirely due to a change in climate dynamics. Until more is understood about the cause of the ozone hole, it is impossible to determine whether the hole is a precursor of atmospheric behavior that will occur in other regions of the world and would therefore lead to modifications to current models. The Antarctic ozone declines, however, do show that the atmosphere is more sensitive to some set of factors (yet unknown) than previously thought. (See page ___.)

17. <u>ADDITIONAL INFORMATION FOR ASSESSING RISKS COULD BE OBTAINED BY IMPROVING TWO-DIMENSIONAL MODELS</u>.

17a. More time-dependent simulations using 2-D models are needed to better understand the significance of uncertainties in trace gas projections. (See page ___.)

17b. Radiative codes need to be added to two-dimensional models to reflect more accurately this potentially significant factor affecting the creation and destruction of ozone. (See page ___.)

17c. Uncertainty analyses focusing on kinetics, cross-sections, and transport should be undertaken. (See page ___.)

17d. Greater efforts are needed by the scientific community to understand the range of possible changes from factors like heterogenous chemistry and dynamical change, rather than focusing primarily on best case models. Model intercomparisons of a wider range of realistic time-dependent scenarios and uncertainties are needed.

18. <u>INCREASES IN THE ABUNDANCE OF CFCs AND OTHER TRACE GASES CAN INCREASE GLOBAL TROPOSPHERIC SURFACE TEMPERATURES. THESE GASES CAN ALTER THE VERTICAL DISTRIBUTION OF OZONE AND INCREASE STRATOSPHERIC WATER VAPOR, THEREBY INFLUENCING GLOBAL WARMING</u>.

18a. Trace gases that act as stratospheric perturbants also are greenhouse gases--as their concentrations increase in the troposphere they will retard the escape of infrared radiation from earth, causing global warming. (See page ___.)

18b. Increases in methane (CH4) will also add water vapor to the stratosphere, thereby enhancing global warming. Methane increases will also add ozone to the troposphere, where it acts as a strong greenhouse gas that will further increase global warming. (See page ___.)

18c. In all scenarios of trace gas growth, except those in which CFC use is phased down, ozone decreases in the stratosphere above 28 km. This allows more ultraviolet radiation to penetrate to lower altitudes, where the "self healing effect" tends to increase ozone to partially compensate for the ozone loss above. In some scenarios in which CFC use grows, sufficient depletion occurs at lower altitudes that ozone eventually decreases at all altitudes. (See page ___.)

18d. Decreases in ozone at approximately 28 km or above will have a warming effect on the earth. There is a small net gain in energy because the increase in ultraviolet radiation (UV-B) allowed to reach the earth's surface more than compensates for the infrared radiation that is allowed to escape due to depletion of ozone above that altitude. (See page ___.)

18e. Below approximately 28 km, increases in ozone are more effective as absorbers of infrared radiation. Consequently, increases in ozone below 28 km also will produce a net warming. In this case, the additional UV blocked by more ozone is less than the additional infrared that is blocked from escaping the earth. Conversely, a decrease in ozone below 28 km will tend to cool the earth's surface. (See page ___.)

18f. The direct effect of column depletion of ozone on global temperatures will depend on the magnitude of the depletion. Until the depletion is of sufficient magnitude that it occurs at the lower part of the column, ozone depletion will be a net contributor to global warming. If the stratosphere continues to deplete so that ozone is depleted below 28 km, this depletion will cause a cooling. One-dimensional models differ from two-dimensional models in the vertical distribution of ozone change, with depletion occurring at all altitudes in the higher latitudes in two-dimensional models, rather than just at high altitudes. Thus, according to 2-D models, the changes in radiative balance will be latitude dependent. At the current time, no studies have been undertaken to determine the net radiative forcing of changes projected by 2-D models. (See page _____.)

18g. Radiative forcing may vary strongly with changes in ozone at different altitudes and latitudes. Consequently, until comparisons are made between the models in terms of their global impact, estimates of the effects of changes in the vertical column of ozone on global warming made with 1-D models must be viewed cautiously. (See page ___.)

19. INCREASES IN TRACE GAS CONCENTRATIONS ASSOCIATED WITH STRATOSPHERIC MODIFICATION ARE LIKELY TO WARM THE EARTH SIGNIFICANTLY.

19a. Two National Academy of Sciences panels have concluded that the equilibrium warming for doubling atmospheric concentrations of CO2, or for an equivalent increase in the radiative forcing of other trace gases, will most likely be between 1.5° and 4.5°C. (See page ___.)

19b. The magnitude of warming that would be directly associated with radiative forcing from increases in trace gases without feedback enhancement would increase temperature by 1.26°C for a doubling of CO2, and an additional 0.45°C for a simultaneous doubling of N2O and CH4. Direct radiative forcing from a uniform 1 ppb increase in CFC-11 and CFC-12 would increase temperature by about 0.15°C. (See page ___.)

19c. The initial warming from direct radiative forcing would change some of the geophysical factors that determine the earth's radiative balance (i.e., feedbacks will occur) and these changes would amplify the initial warming. Increased water vapor and altered albedo effects (snow and ice melting, reducing the reflection of radiation back to space) have been projected by several modeling groups to increase the warming to as much as 2.5°C for doubled CO2 or its radiative equivalent. Large uncertainties exist about the feedbacks between global warming and clouds, which could further amplify, or possibly reduce, the magnitude of warming. (See page ___.)

19d. The three major general circulation modeling groups in the U.S. estimate an average global warming of around 4°C for doubled CO2 or its radiative equivalent. However, because of uncertainties in the representation of the cloud contributions, greater or lesser amplifications, including a negative feedback that would reduce the warming to 2°C or an even lower value, cannot be ruled out. (See page ___.)

19e. Global average temperature has been estimated as having risen about 0.6°C over the last century. This increase is consistent with general predictions of climate models. Attempts to use these data to derive empirically the temperature sensitivity of the earth to a greenhouse forcing are not likely to succeed. Uncertainty about the past concentrations of trace gases in the atmosphere, other exogenous factors that affect the climate (such as aerosols or solar input), and oscillation and instabilities in the internal dynamics of the climate system (such as ocean circulation), currently prevent the derivation of the earth's temperature sensitivity from examination of the historic rise of temperature. This limitation is likely to remain for more than another decade. (See page ___.)

19f. The global warming associated with increases in ozone-modifying gases varies with scenarios of future growth in these gases. If the use of CFCs grows at 2.5 percent per year through 2050, CO2 concentrations grow at the 50th percentile rate defined by the NAS (approximately 0.6 percent per year from 1985 to 2050), N2O concentrations grow at 0.20 percent per year, and CH4 concentrations grow at 0.017 ppm per year (approximately 1.0 percent of current concentrations), then equilibrium temperatures would rise by about 3.8°C by 2050 (relative to observed temperature in 1985), based on a temperature sensitivity of 3°C for doubled CO2. Values would be about 50 percent higher for a 4.5°C-based temperature sensitivity and about 50 percent lower for 1.5°C. If CFC use remains constant through 2050, the projected warming would be about 3.1°C by 2050 (± 50%), and if use were phased out by 2010, projected warming would be about 2.9°C (± 50%). (See page ___.)

19g. Efforts to gather worldwide time series data for clouds have begun. If adequate, these data may narrow estimates of the cloud contribution to temperature sensitivity within the next decade. However, because of the complexity of this issue, this effort may fail to resolve the large uncertainties affecting this aspect of climate. (See page ___.)

20. <u>THE TIMING OF GLOBAL WARMING DEPENDS ON THE RATES AT WHICH GREENHOUSE GASES INCREASE, THE RATES AT WHICH OTHER FORCINGS SUCH AS VOLCANOES AND SOLAR RADIATION CHANGE, AND THE RATE AT WHICH OCEANS TAKE UP HEAT AND PARTIALLY DELAY TEMPERATURE EFFECTS. A GLOBAL WARMING GREATER THAN VARIATIONS THAT OCCURRED THIS PAST CENTURY IS EXPECTED IN THE NEXT TEN YEARS IF VOLCANIC AND SOLAR FORCINGS DO NOT SUBSTANTIALLY CHANGE</u>.

20a. The delay in temperature rise introduced by absorption of heat by the oceans can only be roughly estimated. The simple one-dimensional models of oceans that have been used for this purpose do not realistically portray the mechanisms for heat transport into the oceans. Instead, these models use eddy diffusion to treat heat in a parameterized manner so that heat absorption is consistent with data from the paths of transient tracers. These models indicate that the earth will experience substantial delays in experiencing the full warming from greenhouse gases. (See page ___.)

20b. The earth's current average temperature is not in equilibrium with the radiative forcing from current concentrations of greenhouse gases. Consequently, global average temperature would increase in the future even if concentrations of gases did not rise any further. For example, if 2°C is the actual sensitivity of the earth's climate system to a CO_2 doubling, simple models estimate the current "unrealized warming" to be approximately 0.34°C; for a 4°C temperature sensitivity, the current unrealized warming would be approximately 1.0°C. (See page ___.)

20c. Only one three-dimensional general circulation model has been used to simulate changes in temperature as concentrations of greenhouse gases increase over time. This simulation shows a faster warming than predicted by simpler one-dimensional models that use ocean box models to simulate time-dependent warming. (See page ___.)

20d. Future uptake of heat by the oceans may change as global warming alters ocean circulation, possibly altering the delaying effect of the oceans as well as reducing their uptake of CO_2. (See page __.)

20e. Inadequate information exists to predict how volcanic or solar forcings may change over time. Analyses done of transient warming assume that past levels of volcanic aerosols will continue into the future and that solar forcing changes will average out over relatively short periods of time. (See page ___.)

21. <u>WITH A FEW GENERALIZED EXCEPTIONS, THE CLIMATIC CHANGE ASSOCIATED WITH GLOBAL WARMING CANNOT BE RELIABLY PREDICTED ON A REGIONAL BASIS</u>.

21a. In general, as the earth warms, temperature increases will be greater with increasing distance from the equator. (See page ___.)

21b. Global warming also can be expected to increase precipitation and evaporation, intensifying the hydrological cycle. While models lack sufficient reliability to make projections for any single region, all perturbation studies with three-dimensional models (general circulation models) show significant regional shifts in dryness and wetness, which suggests that significant shifts in hydrologic conditions will take place throughout the world. (See page ___.)

21c. Current general circulation models represent oceanic, biospheric, and cloud processes with insufficient realism to determine how extreme weather events and climatic norms are likely to change on a regional basis. For example, one analysis of general circulation model outputs suggests that the frequency of extreme climatic conditions will change in many regions of the world. Another model projects increased summer drying in mid-latitudes for perturbation studies, utilizing either of two different representations of clouds. Still another analysis suggests changes in latitudinal gradients of sea surface temperature will play a critical role in determining regional effects. (See page ___.)

22. LIMITING GLOBAL WARMING BY REDUCING EMISSIONS OF STRATOSPHERIC PERTURBANTS THAT TEND TO ADD OZONE OR COUNTER DEPLETION WOULD INCREASE THE STRATOSPHERE'S VULNERABILITY TO OZONE DEPLETION. UNDER SCENARIOS IN WHICH CONTINUED BUFFERING OF OZONE DEPLETION BY OTHER TRACE GASES IS ASSUMED, SUBSTANTIAL GLOBAL WARMING RESULTS.

22a. Decreases in substances with the potential to deplete stratospheric ozone--that is, chlorofluorocarbons and nitrous oxides--would decrease the rate and magnitude of global warming. (See page ___.)

22b. Decreases in methane emissions, which have the potential to increase stratospheric and tropospheric ozone and thereby buffer ozone depletion, would decrease warming in three ways: by reducing direct radiative effects from its presence in the troposphere; by lowering water vapor in the stratosphere; and by reducing ozone build-up below 28 km. (See page ___.)

22c. Decreases in CO2 emissions would decrease global warming, but would also have the effect of increasing the stratosphere's vulnerability to ozone depletion. (See page ___.)

22d. Decreases in carbon monoxide concentrations, which may occur as energy production practices change, could result in decreases in methane concentrations by increasing OH-radical abundance which, in turn, would shorten the lifetime of methane. (See page ___.)

23. ADDITIONAL RESEARCH IS NEEDED ON CLIMATE TO REDUCE UNCERTAINTIES ABOUT GLOBAL WARMING ASSOCIATED WITH TRACE GAS GROWTH.

23a. The key to improving the accuracy of estimates of global temperature sensitivity is to acquire a better understanding of the effect of clouds. This recommendation has been made by numerous groups over the last decade; yet research devoted to this issue remains relatively small.

23b. An increased understanding of ocean circulation is critical to improving estimates of timing and regional projections.

23c. The effect of climate on biological systems and soils and their impact on climate must be modeled if regional estimates of climate change are to be developed.

23d. A better understanding of the radiative properties of CFC-113 is needed for estimating the effects of this compound on climate.

23e. Experiments with three-dimensional models that have altered scenarios of vertical ozone need to be undertaken to assess the possible impacts on the magnitude of global warming and on general circulation.

SECTION III

HUMAN HEALTH, WELFARE, AND ENVIRONMENTAL EFFECTS FROM OZONE MODIFICATION AND CLIMATE CHANGE

CHANGES IN COLUMN OZONE ABUNDANCE AND DISTRIBUTION AND A RISE IN GLOBAL TEMPERATURE WOULD BE EXPECTED TO HARM HUMAN HEALTH, WELFARE, AND THE ENVIRONMENT. SOME RISKS CAN BE QUANTIFIED USING RANGES. OTHER RISKS CANNOT BE QUANTIFIED OR DATA NECESSARY FOR QUANTIFICATION ARE AVAILABLE ONLY FOR LIMITED CASE STUDIES.

Ozone shields the earth from UV-B radiation. A decrease in total column ozone will increase to this radiation, especially at its most harmful wavelengths. For the DNA action spectrum, a 1% depletion would increase the weighted UV flux by about 2%. Changes in column ozone and increases in global temperatures could alter many environmental conditions. The findings of this section cover the effects of these changes on human health, ecosystems, crops, materials, air pollution, sea level and other areas that influence human welfare.

24. <u>BASED ON SURVEYS (PARTICULARLY IN THE UNITED STATES AND AUSTRALIA), PROLONGED SUN EXPOSURE IS CONSIDERED TO BE THE DOMINANT RISK FACTOR FOR NONMELANOMA SKIN TUMORS</u>.

24a. Nonmelanoma skin tumors tend to develop in sun-exposed sites (e.g., the head, face, and neck). (See page ___.)

24b. Higher incidence rates occur among groups subject to greater exposure to the sun's rays because of occupations that necessitate their working outdoors. (See page ___.)

24c. A latitudinal gradient exists for UV-B radiation and higher incidence rates of nonmelanoma skin tumors generally occur in geographic areas of relatively high UV radiation exposure. (See page ___.)

24d. Skin pigmentation provides a protective barrier that reduces the incidence of nonmelanoma skin tumors. (See page _____.)

24e. The risk of nonmelanoma skin tumors is highest among genetically predisposed individuals (e.g., those with xeroderma pigmentosum). (See page ___.)

24f. A predisposition to develop nonmelanoma skin tumors exists among light-skinned individuals who are susceptible to sunburn and who have red/blond hair, blue/green eyes, and a Celtic heritage. (See page ___.)

25. <u>AVAILABLE EPIDEMIOLOGIC EVIDENCE SUGGESTS THAT THE TWO MAJOR TYPES OF NONMELANOMA SKIN TUMORS, SQUAMOUS CELL CARCINOMA (SCC) AND BASAL CELL CARCINOMA (BCC), RESPOND DIFFERENTLY TO SOLAR EXPOSURE. IT HAS BEEN HYPOTHESIZED THAT CUMULATIVE UV RADIATION HAS A GREATER EFFECT ON THE DEVELOPMENT OF SCC THAN ON BCC</u>.

25a. The BCC/SCC incidence ratio decreases with decreasing latitude and therefore, increasing UV levels. (See page ___.)

25b. BCC is more likely than SCC to develop on normally unexposed sites (e.g., the trunk) compared to SCC. (See page ___.)

25c. SCC is more likely than BCC to develop on sites receiving the highest cumulative UV radiation doses (e.g., the nose). (See page ___.)

25d. For a given cumulative level of sunlight exposure, the risk of developing SCC may be greater than the risk of developing BCC. (See page ___.)

26. <u>RESULTS FROM SEVERAL EXPERIMENTAL STUDIES SUGGEST THAT UV-B MAY BE THE MOST IMPORTANT COMPONENT OF SOLAR RADIATION THAT CAUSES VARIATIONS IN THE INCIDENCE OF NONMELANOMA SKIN TUMORS</u>.

26a. UV radiation produces malignant nonmelanoma skin tumors in animals. UV-B wavelengths have been shown to be most effective in producing these tumors. (See page ___.)

26b. UV-B has been shown to cause a variety of DNA lesions, to induce neoplastic transformation in cells, and to be a mutagen in both animal and bacterial cells. (See page ___.)

27. <u>SEVERAL RESEARCHERS HAVE INVESTIGATED THE CHANGES IN THE INCIDENCE OF NONMELANOMA SKIN TUMORS THAT MAY RESULT FROM INCREASES IN EXPOSURE TO SOLAR UV RADIATION. GIVEN UNCERTAINTIES, RANGES OF ESTIMATES OF INCREASED INCIDENCE THAT COULD OCCUR WITH DEPLETION ARE ESTIMATED.</u>

27a. The action spectrum for initiation and promotion of basal cell and squamous cell skin cancer have not been precisely determined. Photocarcinogenic studies indicate that the erythema and DNA action spectra span a range likely to encompass that of squamous cell and basal cell skin cancer. The Robertson Berger (RB) meter, while providing useful data for describing ambient UV, does not constitute a biological target as such. (See page ___.)

27b. Several studies have provided estimates of a biological amplification factor, BAF, which is defined as the percent change in tumor incidence that results from a one percent change in UV-B radiation. The results from six studies produced an overall BAF range that is 1.8-2.85 for all nonmelanoma skin tumors. (See page ___.)

27c. BAF estimates are generally higher for males than for females and generally increase with decreasing latitude. In addition, the BAF estimates for SCC are higher than the BAF estimates for BCC. This finding is consistent with observations that the BCC/SCC ratio decreases with decreasing latitude and that BCC is more likely to develop on unexposed sites. (See page ___.)

27d. Optical amplification (the change in UV-B radiation related to ozone depletion) increases the response of these cancers to ozone depletion, because the relevant action spectra increase more than 1 percent for a 1 percent depletion. For example, a 1 percent depletion has an optical amplification of over 2 for the DNA action spectrum. (See page ___.)

27e. Uncertainty exists in the actual doses of solar UV radiation received by populations and in the statistical estimates of the dose-response coefficients. Therefore, a range of estimates must be developed for changes in incidence associated with changes in dose.

27f. No comprehensive studies of nonmelanoma mortality exist. Based on published studies, information obtained from death certificates (which tends to be incomplete), and analyses of metastasis rates, nonmelanoma mortality is less than 1 percent of total cases, with most nonmelanoma deaths attributable to squamous cell cancers. (See page ___.)

27g. Changes in behavior have tended to increase skin cancer incidence and mortality. While some evidence exists that this is reaching a limit, skin cancer rates would, even in the absence of ozone depletion, be likely to rise. Future rates of skin cancer could be reduced if people changed their behavior. Care should be taken, however, in interpreting such a change as a cost-free response.

28. CUTANEOUS MALIGNANT MELANOMA (CMM) IS A SERIOUS LIFE-THREATENING DISEASE THAT AFFECTS A LARGE NUMBER OF PEOPLE IN THE UNITED STATES. THERE ARE SEVERAL HISTOLOGICAL FORMS OF MELANOMA THAT ARE LIKELY TO HAVE SOMEWHAT DIFFERENT ETIOLOGIES AND RELATIONSHIPS TO SOLAR AND UV-B RADIATION.

28a. CMM incidence and mortality is increasing among fair-skinned populations. These increases appear not to be merely the result of improved diagnosis and reporting. (See page ___.)

28b. In 1985, there were an estimated 25,000 cases of CMM and 5,000 fatalities related to melanoma in the United States. In the absence of ozone depletion, the lifetime risk of CMM in the United States is expected to be about 1 in 150. (See page ___.)

29. LIMITATIONS IN THE DATABASE PREVENT CERTAINTY ABOUT THE RELATIONSHIP OF SOLAR RADIATION, UV-B RADIATION, AND CUTANEOUS MALIGNANT MELANOMA.

29a. There currently is no animal model in which exposure to UV-B radiation experimentally induces melanomas. (See page ___.)

29b. There is also no experimental *in vitro* model for malignant transformation of melanocytes. (See page ___.)

29c. No epidemiologic studies of CMM have been conducted in which individual human UV-B exposures (and biologically effective doses of solar radiation) have been adequately assessed. (See page __.)

30. EVALUATION OF THE EPIDEMIOLOGIC AND EXPERIMENTAL DATABASES FOR MELANOMA REQUIRES CLOSE ATTENTION TO THE RELATIONSHIP OF WAVELENGTH AND DOSE AND TO THE VARIATIONS OF SOLAR RADIATION IN THE AMBIENT ENVIRONMENT.

30a. Ozone differentially removes wavelengths of UV-B between 295-320 nm; UV-A (320-400 nm) in wavelengths above 350 nm is not removed, nor is visible light (400-900 nm). Ozone removes all UV-C (i.e., wavelengths less than 295 nm). (See page ___.)

30b. Wavelengths between 295 nm and 300 nm are generally more biologically effective (i.e., damage target molecules in the skin, including DNA) than other wavelengths in the UV-B range and even more so than UV-A radiation. (See page ___.)

30c. Latitudinal variations exist in solar radiation; model predictions indicate that the greatest variability is seen in cumulative UV-B (e.g., monthly doses) followed by peak UV-B (highest one-day doses) and then cumulative UV-A. Peak UV-A does not vary significantly across latitudes up to 60°N. Greater ambient variation also exists in UV-B than UV-A by time of day. (See page ___.)

30d. The biologically effective dose of radiation that actually reaches target molecules depends on the duration of exposure at particular locations, time of day, time of year, behavior (i.e., in terms of clothes and sunscreens), and pigmentation and other characteristics of the skin, including temporary variations (e.g., changes in pigmentation due to tanning). (See page ___.)

30e. Cloudiness and albedo, although causing large variations in the amount of exposure to UV-B and UV-A, do not greatly change the ratio of UV-B to UV-A. (See page ___.)

30f. Ozone depletion is predicted to cause the largest increases in radiation in the 295-299 nm UV-B range, less in the 300-320 nm UV-B range, and UV-A is virtually unaffected. (See page ___.)

30g. Cutaneous malignant melanoma has a number of different histologic types which vary in their relationship to sunlight, site, racial preference and possibly in their precursor lesions. Assessment of incidence by type is not consistent among registries, thus complicating attempts to evaluate the relationship between CMM and solar radiation. (See page ___.)

30h. Melanin is the principal pigment in skin that gives it color; melanin effectively absorbs UV radiation; the darker the skin, the more the basal layer is protected from UV radiation . (See page ___.)

31. <u>A LARGE ARRAY OF EVIDENCE SUPPORTS THE CONCLUSION THAT SOLAR RADIATION IS ONE OF THE CAUSES OF CUTANEOUS MALIGNANT MELANOMA</u>.

31a. Whites, whose skin contain less protective melanin, have higher incidence and mortality rates from CMM than blacks. (See page __)

31b. Light-skinned whites, including those who are unable to tan or who tan poorly, have a higher incidence of CMM than darker-skinned whites. (See page ___.)

31c. Sun exposure leading to sunburn apparently induces melanocytic nevi. (See page ___.)

31d. Individuals who have more melanocytic nevi have a higher incidence of CMM; the greatest risk is associated with a particular type of nevus -- the dysplastic nevus. (See page ___.)

31e. Sunlight induces freckling, and freckling is an important risk factor for CMM. (See page ___.)

31f. Incidence has been increasing in cohorts in a manner consistent with changes in patterns of sun exposure, particularly with respect to increasing intermittent exposure of certain anatomical sites. (See page ___.)

31g. Immigrants who move to sunnier climates have higher rates of CMM than populations who remain in their country of origin. Immigrants develop rates approaching those of prior (but native born) immigrants to the adopted country; this is particularly accentuated in individuals arriving before the age of puberty (10-14 years). (See page ___.)

31h. It has been suggested that CMM risk may be associated with childhood sunburn; however, other evidence suggests that childhood sunburn may reflect an individual's pigmentary characteristics or may be related to nevus development, rather than being a separate risk factor. (See page ___.)

31i. Most studies that have used latitude as a surrogate for sunlight or UV-B exposure have found increases in the incidence or mortality of CMM correlated to proximity to the equator. A recent study of incidence using measured UV-B and CMM survey data found a strong relationship between UV-B and incidence of CMM. Another study that used modeled UV-B data and an expanded database on mortality found a strong UV-B/mortality relationship. (See page ___.)

31j. One form of CMM, Hutchinson's melanotic freckle, appears almost invariably on the chronically sun-damaged skin of older people. (See page ___.)

32. <u>SOME EVIDENCE CREATES UNCERTAINTY ABOUT THE RELATIONSHIP BETWEEN SOLAR RADIATION AND CUTANEOUS MALIGNANT MELANOMA</u>.

32a. Some ecologic epidemiology studies, primarily in Europe or close to the equator, have failed to find a latitudinal gradient for CMM. (See page ___.)

32b. Outdoor workers generally have lower incidence and mortality rates for CMM than indoor workers, which appears incompatible with a hypothesis that cumulative dose from solar exposure causes CMM. (See page ___.)

32c. Unlike basal cell and squamous cell carcinomas, most CMM occurs on sites that are not habitually exposed to sunlight; this contrast suggests that cumulative exposure to solar radiation or UV-B is not solely responsible for variations in CMM. (See page ___.)

33. UV-B RADIATION IS A LIKELY COMPONENT OF SOLAR RADIATION THAT CAUSES CUTANEOUS MALIGNANT MELANOMA (CMM), EITHER THROUGH INITIATION OF TUMORS OR THROUGH SUPPRESSION OF THE IMMUNE SYSTEM.

33a. Xeroderma pigmentosum patients who fail to repair UV-B-induced pyrimidine dimers in their DNA have a 2,000-fold excess rate of CMM by the time they are 20. (See page ___.)

33b. UV-B is the most active part of the solar spectrum in the induction of mutagenesis and transformation *in vitro*. (See page ___.)

33c. UV-B is the most active part of the solar spectrum in the induction of carcinogenesis in experimental animals and is considered to be a causative agent of nonmelanoma skin cancer in humans. (See page ___.)

33d. UV-B is the most active portion of the solar spectrum in inducing immunosuppression which may have a role in melanoma development. (See page ___.)

33e. The limitations in the epidemiologic and experimental database leave some doubt as to the effectiveness of UV-B wavelengths in causing CMM. (See page ___.)

34. WHILE UNCERTAINTY EXISTS, INCREASES IN THE INCIDENCE AND MORTALITY OF CUTANEOUS MALIGNANT MELANOMA ARE LIKELY AS A RESULT OF OZONE DEPLETION. WHILE MANY UNCERTAINTIES EXIST (E.G., REGARDING ACTION SPECTRA, PEAK VERSUS CUMULATIVE DOSE, ETC.) ABOUT THE NATURE OF THE RELATIONSHIP BETWEEN UV-B AND MELANOMA, THE FACT THAT UV-B RADIATION VARIES ACROSS THE ENVIRONMENT IN THE RANGE OF VARIATION EXPECTED FROM DEPLETION PROVIDES INFORMATION USUALLY UNAVAILABLE TO RESEARCHERS MAKING QUANTITATIVE RISK ESTIMATES. THUS ALTHOUGH IMPERFECT, EPIDEMIOLOGIC INFORMATION EXISTS TO ESTIMATE A RANGE OF CHANGES IN INCIDENCE AND MORTALITY IF THE OZONE LAYER IS DEPLETED.

34a. Uncertainty exists about the appropriate action spectrum to be used in estimating dose, the best functional form for dose-response, the best way to characterize dose (peak value, cumulative exposure, etc.) and the relative importance of UV-B as an initiator or promoter. Histologically-different CMMs (or possibly CMM located at different anatomical sites) are likely to have different dose-response relationships. Most estimates of CMM dose-response relationships fail to consider these histological or site differences. Nonetheless, by encompassing a range of possibilities it is possible to estimate dose-response because of the systematic variations in UV-B. (See page ___.)

34b. A recent study by the NIH presents a well-designed ecological study of melanoma and UV-B using survey data and measured UV-B at ground levels. While much uncertainty exists, this dose-response relationship, when used with different action spectra and assumptions about the importance of peak versus cumulative exposure, can be utilized to estimate a range of values for cases. The relationship estimates that a 1 percent change in ozone is likely to increase incidence by between slightly less than 1 to 2 percent, depending on the choice of action spectrum. The appropriate action spectrum is likely to be encompassed in the range of erythema and DNA. (See page ___.)

34c. Melanoma mortality is estimated at about 25 percent of all cases. This result is consistent with the projections of a dose-response model of mortality developed by EPA/NCI. It is estimated that a 1 percent change in ozone would result in a 0.8 - 1.5 percent change in CMM mortality. (See page ___.)

34d. Additional uncertainties in projecting future incidence and mortality of CMM in the U.S. include the lack of an adequate database describing variations in skin pigmentation and human sun-exposure behavior among different populations and estimates of how these relationships may change in the future. (See page ___.)

35. <u>UV-B SUPPRESSES THE IMMUNE SYSTEM IN ANIMAL EXPERIMENTS</u>.

35a. Acute high doses of UV radiation cause a panimmunosuppression that is short lived. (See page ___.)

35b. UV radiation administered in relatively low doses also causes a depression in cell-mediated immunity, which results in an inability to respond to an antigen which is presented to the animal through the UV irradiated skin, a depression of contact hypersensitivity. (See page ___.)

35c. High doses of UV radiation cause a depression in cell-mediated immunity, leading to delayed-type hypersensitivity. This results in an inability of the animal to respond to an antigen which is presented through irradiated skin. (See page ___.)

35d. Both the effects of the local depression of contact hypersensitivity and the systemic suppression of contact hypersensitivity are mediated by a T suppressor cell which prevents the development of active immunity to the antigen. (See page ___.)

35e. The immunosuppressive effects of UV radiation have been found to reside almost entirely in the UV-B wavelengths. (See page ___.)

36. SUPPRESSION OF THE IMMUNE SYSTEM MAY PLAY AN IMPORTANT ROLE IN CARCINOGENESIS.

36a. Animals that are UV-irradiated also develop T suppressor cells which interfere with the immune response to UV-induced tumors, resulting in animals that are more susceptible to the growth of autochthonous UV-induced tumors. The suppression of the immune system that would result from ozone depletion is reflected in dose-response estimates of photocarcinogenesis. (See page ___.)

37. LIMITED EXPERIMENTAL DATA INDICATE THAT UV-B SUPPRESSES THE HUMAN IMMUNE SYSTEM.

37a. Although there is limited information about the effects of UV radiation on humans, several studies indicate that the immune response of humans is depressed by UV radiation and is depressed in UV-irradiated skin. (See page ___.)

38. UV-B-INDUCED SUPPRESSION OF THE HUMAN IMMUNE SYSTEM IS LIKELY TO HAVE A DELETERIOUS EFFECT WITH REGARD TO MANY HUMAN DISEASES.

38a. Preliminary studies indicate that UV radiation may prevent an effective immune response to micro-organisms that infect via the skin, thus predisposing to reinfection or chronic infection. (See page ___.)

38b. Two human diseases that may be influenced by UV-B-induced immune suppression are herpes virus infections and leishmaniasis. (See page ___.)

38c. Almost no research has been conducted on the influence of UV-B on other infectious diseases; additional investigation is clearly warranted. (See page ___.)

38d. For at least one theory of the mechanisms of UV-B suppression of the immune system (that involving urocanic acid), a possibility exists that non-whites, as well as whites, would be vulnerable to increased immune suppression caused by ozone depletion. (See page ___.)

38e. Because UV-B can produce systemic immunologic change, the possibility exists that changes in UV-B could have effects beyond cutaneous skin infections and skin cancers. (See page ___.)

38f. Immunologic studies to date have not assessed the effects of long-term chronic UV-B irradiation. Consequently, the magnitude of this risk cannot be assessed. (See page ___.)

39. <u>EVIDENCE EXISTS SUGGESTING THAT CATARACT INCIDENCE WILL CHANGE WITH ALTERATIONS IN THE FLUX OF UV-B CAUSED BY OZONE DEPLETION</u>.

39a. Many possible mechanisms exist for formation of cataracts. UV-B may play an important role in some mechanisms. (See page ___.)

39b. Although the cornea and aqueous of the human eye screen out significant amounts of UV-A and UV-B radiation, nearly 50 percent of radiation at 320 nm is transmitted to the lens. Transmittance declines substantially below 320 nm, so that less than 1 percent is transmitted below approximately 290 to 300 nm. However, the results of laboratory experiments on animals indicate that short wavelength UV-B (i.e., below 290 nm) is perhaps 250 times more effective than long wavelength UV-B (i.e., 320 nm) in inducing cataracts. (See page ___.)

39c. In laboratory animal experiments, the action spectrum for inducing cataracts is weighted heavily in the UV-B range. (See page ____.)

39d. Human cataract prevalence appears to vary with latitude and UV radiation; brunescent nuclear cataracts show the strongest relationship. (See page ___.)

40. <u>INCREASES IN THE AMOUNT OF UV-B THAT CAN REACH THE RETINA APPEAR CAPABLE OF CAUSING STABLE RETINAL DISORDERS AND RETINAL DEGENERATION, TWO CAUSES OF BLINDNESS</u>.

41. <u>LIMITED STUDIES HAVE ANALYZED THE EFFECT OF INCREASED UV-B RADIATION ON PLANTS. STUDIES GENERALLY SHOW ADVERSE IMPACTS; HOWEVER BECAUSE OF DIFFICULTIES IN EXPERIMENTAL DESIGN, THE LARGE NUMBER OF SPECIES AND CULTIVARS, AND COMPLEX INTERACTIONS BETWEEN PLANTS AND THEIR ENVIRONMENT, CONCLUSIONS ABOUT THE AMOUNT OF YIELD LOSSES ATTRIBUTABLE TO UV-B CANNOT BE DRAWN</u>.

42. <u>OF PLANT CULTIVARS TESTED IN THE LABORATORY, APPROXIMATELY 70 PERCENT WERE DETERMINED TO BE SENSITIVE TO UV-B</u>.

42a. Laboratory experiments have been shown to replicate inadequately effects in the field. In some species, mitigation responses (e.g., increased production of flavonoids) have reduced adverse impacts.

42b. Different cultivars within a species have exhibited different degrees of UV-B sensitivity. While this suggests selective breeding could limit damage, neither the basis for selectivity nor the potential effect on other aspects of growth has been studied.

43. <u>THE EFFECTS OF UV-B RADIATION HAVE BEEN EXAMINED FOR ONLY FOUR OF THE TEN MAJOR TERRESTRIAL ECOSYSTEMS AND FOR ONLY A THIRD OF THE PLANT GROWTH FORMS</u>.

43a. Little or no data exist on enhanced UV-B effects on trees, woody shrubs, vines, or lower vascular plants. (See page ___.)

43b. Because of a lack of data it is impossible to adequately address the question of the effects of UV-B changes on plants either within the United States or on a global basis. (See page ___.)

44. LARGE UNCERTAINTIES EXIST AS A RESULT OF AN IMPERFECT EXPERIMENTAL DESIGN OR DOSIMETRY. EXISTING EXPERIMENTAL FIELD DATA SUGGEST A POTENTIAL REDUCTION IN CROP YIELD DUE TO ENHANCED UV-B RADIATION.

44a. Field experiments have sometimes not adequately controlled UV-B dose, soil temperature, or other parameters, and because natural conditions (e.g., precipitation, ambient temperature) vary, determining a dose-response relationship is further complicated.

44b. The only long-term field studies of a crop involved soybeans. These studies have found that enhanced levels of UV-B, simulating between 16 and 25 percent ozone depletion, caused crop yield reductions of up to 25 percent in a particular cultivar. Smaller reductions in yield were experienced in years where drought conditions existed. (See page ___.)

44c. Soybean (CV Essex) yield could be accurately predicted when total UV-B dose, daily maximum temperature, and number of days of precipitation were included in a regression model. (See page ___.)

44d. The lipid and protein content of soybean was reduced up to 10 percent; however, higher UV-B doses alone did not consistently result in the largest reductions. (See page ___.)

44e. Two out of three soybean cultivars tested under laboratory conditions were sensitive to UV-B. If this relationship holds true in the field, it suggests (when considered in light of yield reduction experiments) that UV-B increases could harm the potential of the would agricultural system to produce soybeans.

45. THE EFFECTS OF UV-B ON FUNGAL OR VIRAL PATHOGENS VARY WITH PATHOGEN, PLANT SPECIES, AND CULTIVAR.

45a. Reduced vigor in UV-sensitive plants could render the plants more susceptible to pest or disease damage and thus result in reductions in crop yield. (See page ___.)

45b. Current evidence on possible interactions with pathogens is very limited. (See page ___.)

46. CHANGES IN UV-B LEVELS MAY INDUCE SHIFTS IN BOTH INTER- AND INTRASPECIFIC COMPETITION.

46a. If enhanced UV-B favors weeds over crops, agricultural costs (e.g. for increased tilling and herbicide application) could increase. However, insufficient evidence exists to form a basis for evaluating this effect. (See page ___.)

46b. Increases in UV-B could alter the results of the competition in natural ecosystems and thus shift community composition. (See page ___.)

47. <u>UV-B RADIATION INHIBITS AND STIMULATES FLOWERING, DEPENDING ON THE SPECIES AND GROWTH CONDITIONS.</u>

47a. The timing of flowering may also be influenced by UV-B radiation, and pollen may be susceptible to UV damage upon germination. (See page ___.)

47b. Reproductive structures enclosed within the ovary appear to be well-protected from UV-B radiation. (See page ___.)

48. <u>INTERACTIONS BETWEEN UV-B RADIATION AND OTHER ENVIRONMENTAL FACTORS ARE IMPORTANT IN DETERMINING POTENTIAL UV-B EFFECTS ON PLANTS</u>.

48a. UV-B effects may be worsened under low light regimes or suppressed under conditions of limited nutrients or water. (See page ___.)

48b. Interactions with other environmental effects make extrapolation of data from growth chambers or greenhouses to field conditions difficult and often unreliable. (See page ___.)

48c. The combined effect of higher UV-B and other environmental changes cannot be adequately assessed by current data. Extensive, long-term sutides would be required. (See page ___.)

49. <u>INITIAL EXPERIMENTS SHOW THAT REDUCTIONS IN STRATOSPHERIC OZONE, WHICH INCREASES SOLAR ULTRAVIOLET RADIATION, HAVE THE POTENTIAL TO HARM AQUATIC LIFE. DIFFICULTIES IN EXPERIMENTAL DESIGNS AND THE LIMITED SCOPE OF THE STUDIES PREVENT THE QUANTIFICATION OF RISKS</u>.

49a. Increases in energy in the 290-320 nm wavelengths that would occur if the ozone layer were depleted could harm aquatic life. (See page ___.)

49b. Based on the DNA action spectrum, a 10 percent ozone decrease would result in a 28 percent increase in biologically effective radiation, the radiation that appears most relevant to aquatic organisms. (See page ___.)

49c. A 10 percent decrease in column ozone would produce an increase in biologically effective radiation comparable to forcing aquatic organisms to migrate over 30° of latitude. (See page ___.)

50. <u>LIMITED EXPERIMENTAL DATA DEMONSTRATE A RISK TO AQUATIC LIFE</u>.

50a. Various experiments have shown that UV-B radiation damages fish larvae and juveniles, shrimp larvae, crab larvae, copepods, and plants essential to the marine food web. (See page ___.)

50b. Up to some threshold level of exposure, most zooplankton show no effect due to increased exposure to UV-B radiation. However, exposure above the dose threshold elicits significant and irreversible physiological and behavioral effects. (See page ___.)

50c. While the exact limits of tolerance and current exposure have not been precisely determined, estimates of these two properties for a variety of aquatic organisms show them to be essentially equal. (See page ___.)

50d. The equality of tolerance and exposure suggests that solar UV-B radiation is currently an important limiting ecological factor, and the sunlight-exposed organisms sacrifice potential resources to avoid increased UV-B exposure. Thus, even small increases of UV-B exposure would be likely to further injure species currently under UV-B stress. (See page _____.)

50e. A decrease in column ozone is reasonably likely to diminish the near-surface season in which zooplankton can survive or breed. Whether the population could endure a significant shortening of the surface season is unknown (e.g., for some zooplankton the surface season is critical for breeding). (See page ___.)

50f. Sublethal exposure of copepods produces a reduction in fecundity. (See page ___.)

50g. Of the animals tested, no zooplankton possess a sensory mechanism for directly detecting UV-B radiation; therefore, it would be unlikely that they would actively avoid enhanced levels of exposure resulting from a reduction in column ozone. (See page ____.)

50h. Exposure of a community to UV-B stress in controlled experiments has resulted in a decrease in species diversity, and therefore a possible reduction in ecosystem resilience and flexibility. (See page ___.)

50i. One experiment predicted an 8 percent annual loss of the larval anchovy population from a 9 percent reduction in column ozone in a marine system with a 10-meter mixed layer. (See page ___.)

51. <u>SIGNIFICANT LIMITATIONS EXIST IN PROJECTING DAMAGE TO AQUATIC SYSTEMS FROM CHANGES IN ULTRAVIOLET RADIATION</u>

51a. Because aquatic organisms are small and do not usually have fixed locations, it is very difficult to obtain accurate data needed to model the systems and verify results. Understanding of the life cycle of organisms is very limited. (See page ___.)

52. <u>IN COMMON WITH ALL OTHER LIVING ORGANISMS, THE AQUATIC BIOTA COPE WITH SOLAR UV-B RADIATION BY AVOIDANCE, SHIELDING, AND REPAIR MECHANISMS. UNCERTAINTY EXISTS AS TO HOW MUCH SUCH BEHAVIOR COULD REDUCE DAMAGE.</u>

53. DETERMINATION OF UV-B EXPOSURE IN AQUATIC SYSTEMS IS MORE COMPLEX THAN FOR TERRESTRIAL ECOSYSTEMS BECAUSE OF THE VARIABLE ATTENUATION OF UV-B RADIATION IN THE WATER COLUMN.

54. CURRENT DATA ONLY INDICATE PROBABLE TRENDS FOR AQUATIC SYSTEMS AND ARE BASED ON INCOMPLETE AND LIMITED OBSERVATIONS; CONSEQUENTLY, THEY MUST BE REGARDED AS VERY TENTATIVE. THE POSSIBILITY EXISTS THAT THE RISKS FROM UV-B RADIATION ARE SMALLER OR LARGER THAN CURRENT EXPERIMENTAL EVIDENCE APPEARS TO INDICATE.

55. INCREASED UV-B RADIATION WILL ACCELERATE THE DEGRADATION OF POLYMERS.

55a. Several commercial polymers (e.g., polyethylene, polypropylene, poly(vinylchloride)), although theoretically UV transparent, contain chromophore impurities that absorb light in the UV-B region of the spectrum. Other polymers (e.g., polycarbonate) have structural features in their molecules that result in strong UV-B light absorption. (See page ___.)

55b. Several polymers have important outdoor applications (e.g., used in siding and window glazing in the building industry; in film and containers in packaging; in housewares and toys; and in paints and protective coatings). Such polymers are likely to be exposed to significant amounts of UV-B radiation. Other polymers are stored outside before use and could deteriorate during these periods. (See page ___.)

55c. Absorption of UV-B radiation in polymers causes photo-induced reactions and alters important mechanical, physical, or optical properties of the polymers (e.g., yellowing, brittleness) and thus degrades (i.e., reduces the useful life of) the polymers. (See page ______.)

56. UV-STABILIZERS ARE USED IN POLYMERS FOR PROTECTION AGAINST UV RADIATION. INCREASED UV-B RADIATION MAY REQUIRE INCREASED USAGE OF STABILIZERS TO MAINTAIN A PRODUCT'S USEFUL LIFE.

56a. Increased amounts of stabilizers might adversely affect the processing and use properties of some polymers (e.g., hardness, thermal conductivity, flow characteristics). For example, increased amounts of titanium dioxide in poly(vinylchloride) might affect its processing properties, increasing its costs of production. (See page ___.)

56b. Changes in the amount of stabilizer (and other additives) would increase costs of products or could require development of new formulations to avoid or minimize impurities in production. (See page ___.)

56c. The addition of stabilizers to polymers may be limited by practical problems of material characteristics or manufacture. However, other responses may be possible to limit damage. (See page ___.)

57. POTENTIAL DAMAGES TO POLYMERS RELATED TO OZONE DEPLETION AND CLIMATE CHANGE ARE DIFFICULT TO ESTIMATE.

57a. Due to lack of relevant experimental data, only approximate estimation methods are available to determine the potential extent of light-induced damage. (See page ___.)

57b. Depending upon the chemical nature of a polymer, the components of the compound, and the weathering factors, both temperature and humidity tend to increase the rate of degradation. (See page __.)

58. INCREASED UV-B RADIATION DUE TO OZONE DEPLETION COULD HAVE ADVERSE ECONOMIC EFFECTS.

58a. Changes in polymer processing properties can result in more equipment shutdowns, higher maintenance costs, and increased utility costs. (See page ___.)

58b. Increased operating costs and material costs (e.g., for stabilizers, lubricants, and other additives) would have an adverse economic impact on the polymer/plastic industry and related industries. (See page ___.)

58c. In a case study using preliminary data and methods, and a given scenario of ozone depletion (26% depletion by 2075), undiscounted cumulative (1984-2075) economic damage for poly(vinylchloride) is estimated at $4.7 billion (USA only). Due to the lack of data, possible damage to other polymers has not been assessed. (See page ___.)

59. RESULTS FROM ONE MODELING STUDY AND ONE CHAMBER STUDY SUGGEST THAT INCREASED ULTRAVIOLET RADIATION FROM OZONE DEPLETION MAY INCREASE THE RATE OF TROPOSPHERIC OZONE FORMATION.

59a. According to these studies, increases in UV-B associated with ozone depletion would increase the quantity of ground-based ozone associated with various hydrocarbon and nitrogen oxides emission levels. Results for individual cities vary, depending on the city's location and on the exact nature of the pollution. (See page ___.)

59b. According to these studies, global warming would enhance the effects of increased UV-B radiation on the formation of ground-based ozone. (See page ___.)

59c. According to these studies, ground-based ozone would form earlier in the day. This would cause larger populations in some cities to be exposed to peak values. (See page ___.)

59. More research is needed to verify and expand the results of these studies.

60. PRELIMINARY RESULTS FROM ONE STUDY ALSO SUGGEST THAT LARGE INCREASES IN HYDROGEN PEROXIDE WOULD RESULT FROM INCREASED UV-B RADIATION.

60a. If hydrogen peroxide increases as predicted in this study, the oxidation potential of the atmosphere, including the formation of acid rain, would be influenced. (See page ___.)

60b. More research, especially a chamber study, is needed to verify this effect.

61. INCREASES IN GROUND-BASED OZONE WOULD ADVERSELY AFFECT PUBLIC HEALTH AND WELFARE.

61a. If UV-B increases enhanced ozone production, more U.S. cities would be unable to meet health-based ground-level ozone standards, and background ozone would increase. (See page ___.)

61b. Crops, ecosystems, and materials would be adversely affected by increased ground-level ozone. (See page ___.)

62. GLOBAL AVERAGE SEA LEVEL APPEARS TO HAVE RISEN 10 TO 15 CM OVER THE LAST CENTURY.

62a. Studies of the possible contribution of thermal expansion and alpine meltwater to sea level rise, based on the 0.6°C warming of the past century, indicate that these two sources are insufficient to explain the estimated sea level rise that has occurred during this period. (See page ___.)

62b. No cause and effect between global warming and past sea level has been conclusively demonstrated. (See page ___.)

63. THE PROJECTED GLOBAL WARMING WOULD ACCELERATE THE CURRENT RATE OF SEA LEVEL RISE BY EXPANDING OCEAN WATER, MELTING ALPINE GLACIERS, AND EVENTUALLY INCREASING THE RATE AT WHICH POLAR ICE SHEETS MELT OR DISCHARGE ICE INTO THE OCEANS.

64. ESTIMATES OF THE RISE IN SEA LEVEL THAT COULD TAKE PLACE IF MEASURES TO LIMIT THE GLOBAL WARMING ARE NOT UNDERTAKEN RANGE FROM 10 TO 20 CM BY THE YEAR 2025, AND 50 TO 200 CM BY 2100.

64a. Thermal expansion alone would increase sea level rise between about 30 cm and 100 cm by 2100, depending on the realized temperature change. This is the most certain contribution. (See page ___.)

64b. Melting of alpine glaciers and possibly of ice on Greenland could each contribute 10 to 30 cm through 2100, depending on the scenario. This contribution also has a high degree of likelihood (See page ___.)

64c. The contribution of Antarctic deglaciation is more difficult to project. It has been estimated at between 0 and 100 cm; however, the possibilities cannot be ruled out that (1) increased snowfall could increase the size of the Antarctic ice sheet and thereby partially offset part of the sea level rise from other sources; or (2) meltwater and enhanced calving of the ice sheet could increase the contribution of Antarctic deglaciation to as much as 2 m. The Antarctic contribution to sea level rise may be more sensitive to time delays after certain threshold conditions are reached than to the magnitude of total warming. (See page ___.)

65. <u>OVER THE MUCH LONGER TERM (THE NEXT FEW CENTURIES) DISINTEGRATION OF THE WEST ANTARCTIC ICE SHEET MIGHT RAISE SEA LEVEL BY 6 METERS</u>.

65a. Glaciologists generally believe that such a disintegration of the west Antarctic ice sheet would take at least 300 years, and probably at least 500 years. (See page ___.)

65b. A global warming might result in sufficient thinning of the Ross and Filcher-Ronne Ice Shelves in the next century to make the process of disintegration irreversible. (See page ___.)

66. <u>LOCAL TRENDS IN SUBSIDENCE AND EMERGENCE MUST BE ADDED OR SUBTRACTED TO GLOBAL RISK ESTIMATES IN ORDER TO ESTIMATE SEA LEVEL RISE AT PARTICULAR LOCATIONS.</u>

66a. Most of the Atlantic and Gulf Coasts of the United States--as well as the Southern Pacific coast--are subsiding 10-20 cm per century. (See page ___.)

66b. Louisiana is subsiding 1 m per century, while parts of Alaska are emerging 10-100 cm per century. (See page ___.)

67. <u>A SUBSTANTIAL RISE IN SEA LEVEL WOULD PERMANENTLY INUNDATE WETLANDS AND LOWLANDS, ACCELERATE COASTAL EROSION, EXACERBATE COASTAL FLOODING, AND INCREASE THE SALINITY OF ESTUARIES AND AQUIFERS</u>.

67a. Louisiana is the state most vulnerable to a rise in sea level. Important impacts would also occur in Florida, Maryland, Delaware, New Jersey, and in the coastal regions of other states. (See page ___.)

67b. A rise in sea level of 1 to 2 m by the year 2100 could destroy [illegible] percent to 80 percent of U.S. coastal wetlands. (See page ___.)

67c. Limited studies predict that increased salinity from sea level rise would convert cypress swamps to open water and threaten drinking water supplies in areas such as Louisiana, Phildelphia, and New Jersey. Other areas, such as Southern Florida, may also be vulnerable but have not been investigated. (See page ___.)

68. EROSION PROJECTED IN VARIOUS STUDIES TO RESULT FROM ACCELERATED SEA LEVEL RISE COULD THREATEN U.S. RECREATIONAL BEACHES.

68a. Case studies of beaches in New Jersey, Maryland, California, South Carolina, and Florida have concluded that a 30-cm rise in sea level would result in beaches eroding 20-60 m or more. Major beach preservation efforts would be required if recreational beaches are to be maintained. (See page ___.)

69. ACCELERATED SEA LEVEL RISE WOULD INCREASE THE DAMAGES FROM FLOODING IN COASTAL AREAS.

69a. Flood damages would increase because higher water levels would provide a higher base for storm surges. (See page ___.)

69b. Erosion would increase the vulnerability to storm waves, and decreased natural and artificial drainage would increase flooding during rainstorms. (See page ___.)

70. ESTIMATES OF DAMAGE FROM SEA LEVEL RISE MUST CONSIDER POSSIBLE MITIGATION BY HUMAN RESPONSES.

70a. The adverse impacts of sea level rise could be ameliorated through anticipatory land use planning and structural design changes. (See page ___.)

70b. In a case study of two cities, Charleston, South Carolina and Galveston, Texas accelerated anticipatory planning was estimated to reduce net damages by 20 to 60 percent. (See page ___.)

71. RELATED IMPACTS OF A GLOBAL WARMING WOULD ALSO AFFECT IMPACTS OF SEA LEVEL RISE.

71a. Increased droughts might amplify the salinity impacts of sea level rise. (See page ___.)

71b. Increased hurricanes and increased rainfall in coastal areas could amplify flooding from sea level rise. (See page ___.)

71c. Warmer temperatures might impair peat formation of salt marshes and would enable mangrove swamps to take over areas that are presently salt marsh. (See page ___.)

71d. Decreased northeasterners might reduce damage. (See page __.)

72. RIVER DELTAS THROUGHOUT THE WORLD WOULD BE VULNERABLE TO A RISE IN SEA LEVEL, PARTICULARLY THOSE WHERE RIVERS ARE DAMMED OR LEVEED.

73. <u>CLIMATE CHANGE HAS HAD A SIGNIFICANT IMPACT ON FORESTS IN THE PAST. IF CURRENT PREDICTIONS PROVE ACCURATE, THERE IS A POTENTIAL FOR DRAMATIC SHIFTS IN FORESTS AND VEGETATION OVER THE NEXT 100 YEARS.</u>*

73a. Climate models predict that a global warming of approximately 1.5°C to 4.5°C will be induced by a doubling of atmospheric CO_2 and other trace gases during the next 50 to 100 years. The period 18,000 to 0 years B.P. is the only general analog for a global climate change of this magnitude. The geological record from this glacial to inter-glacial interval provides a basis for qualitatively understanding how vegetation may change in response to large climatic change. (See page ___.)

73b. The paleovegetational record shows that climatic change as large as that expected to occur in response to CO_2 doubling is likely to induce significant changes in the composition and patterns of the world's biomes. Changes of 2°C to 4°C have been significant enough to alter the composition of biomes, and to cause new biomes to appear and others to disappear. At 18,000 B.P., the vegetation in eastern North America was quite distinct from that of the present day. The cold/dry climate of that time seems to have precluded the widespread growth of birch, hemlock, beech, alder, hornbeam, ash, elm, and chestnut, all of which are fairly abundant in present-day deciduous forest. Southern pines were limited to grow with oak and hickory in Florida. (See page ___.)

73c. Available paleoecological and paleoclimatological records do not provide an analog for the high rate of climate change and unprecedented global warming predicted to occur over the next century. Previous changes in vegetation have been associated with climates that were nearly 5°C to 7°C cooler and took thousands of years to evolve rather than decades, the time during which such changes are now predicted to occur. Insufficient temporal resolution (e.g., via radiocarbon dates) limits our ability to analyze the decadal-scale rates of change that occurred prior to the present millennium. (See page ___.)

73d. Limited experiments conducted with dynamic vegetation models for North America suggest that decreases in net biomass may occur and that significant changes in species composition are likely. Experiments with one model suggest that eastern North American biomass may be reduced by 11 megagrams per hectare (10% of live biomass) given the equivalent of a doubled CO_2 environment. Plant taxa will respond individualistically rather than as whole communities to regional changes in climate variables. At this time

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* Findings 73 to 76 are summarized from Appendix B, which provides a comprehensive review of potential impacts of global climate change.

such analyses must be treated as only suggestive of the kinds of change that could occur. Many critical processes are simplified or omitted and the actual situation could be worse or better. (See page ___.)

73e. Future forest management decisions in major timber-growing regions are likely to be affected by changes in natural growing conditions. For example, one study suggests that loblolly pine populations are likely to move north and northeast into Pennsylvania and New Jersey, while its range shrinks in the west. The total geographic range of the species may increase, but a net loss in productivity may result because of shifts to less accessible and less productive sites. While the extent of such changes is unclear, adjustments will be needed in forest technology, resource allocation, planning, tree breeding programs, and decision-making to maintain and increase productivity. (See page ___.)

73f. Dynamic vegetation models based on theoretical descriptions of all factors that could influence plant growth must be improved and/or developed for all major kinds of vegetation. In order to make more accurate future predictions, these models must be validated using the geological record and empirical ecological response surfaces. In particular, the geological record can be used to test the ability of vegetation models to simulate vegetation that grew under climate conditions unlike any of the modern day conditions. (See page ___.)

73g. Dynamic vegetation models should incorporate direct effects of atmospheric CO_2 increases on plant growth and other air pollution effects. Improved estimates of future regional climates are also required in order to make accurate predictions of future vegetation changes. (See page ___.)

74. AGRICULTURE IS VERY DEPENDENT ON CLIMATE. LIMITED ASSESSMENTS SUGGEST THAT IMPORTANT CHANGES IN AGRICULTURE AND FARM PRODUCTIVITY ARE LIKELY THROUGHOUT THE WORLD, IF CLIMATE CHANGE OCCURS AS PREDICTED. ESTIMATES OF IMPACTS ON SPECIFIC REGIONS ARE DIFFICULT TO MAKE BECAUSE REGIONAL PROJECTIONS OF CHANGE CANNOT BE RELIABLY MADE. CURRENT CLIMATIC KNOWLEDGE IS ONLY SUFFICENT TO SUPPORT VULNERABILITY STUDIES FOR ALTERNATIVE SCENARIOS.

74a. Climate has had a significant impact on farm productivity and geographical distribution of crops. Examples include the 1983 drought, which contributed to a nearly 30 percent reduction in corn yields in the U.S.; the persistent Great Plains drought between 1932-1937, which contributed to nearly 200,000 farm bankruptcies; and the climate shift of the Little Ice Age (1500-1800), which led to the abandonment of agricultural settlements in Scotland and Norway. (See page ___.)

74b. World agriculture is likely to undergo significant shifts if trace-gas-induced climate warming in the range of 1.5°C to 4.5°C occurs over the next 50 to 100 years. Climatic effects on agriculture will extend from local to regional and international levels. However, modern agriculture is very dynamic and is constantly responding to changes in production, marketing, and government programs. (See page ___.)

74c. The main effects likely to occur at the field level will be physical impacts of changes in thermal regimes, water conditions, and pest infestations. High temperatures have caused direct damage to crops such as wheat and corn; moisture stress, often associated with elevated temperatures, is harmful to corn, soybean, and wheat during flowering and grain fill; and increased pests are associated with higher, more favorable temperatures. (See page ____.)

74d. Even relatively small increases in the mean temperature can increase the probability of harmful effects in some regions. Analysis of historical data has shown that an increase of 1.7°C (3°F) in mean temperature changes by about a factor of three the likelihood of a five-consecutive-day maximum temperature event of at least 35°C (95°F) occurring in a city like Des Moines. In regions where crops are grown close to their maximum tolerance limits, extreme temperature events may have significant harmful effects on crop growth and yield. (See page ___.)

74e. Limited experiments using climate scenarios and agricultural productivity models have demonstrated the sensitivity of agricultural systems to climate change. Future farm yields are likely to be affected by climate because of changes in the length of the growing season, heating units, extreme winter temperatures, precipitation, and evaporative demand. In addition, field evaluations show that total productivity is a function of the drought tolerance of the land and the moisture reserve, the availability of land, the ability of farmers to shift to different crops, and other factors. (See page ___.)

74f. The transition costs associated with adjusting to global climatic change are not easily calculated, but are likely to be very large. Accommodating to climate change may require shifting to new lands and crops, creating support services and industries, improving and relocating irrigation systems, developing new soil management and pest control programs, and breeding and introducing new heat- or drought-tolerant species. The consequences of these decisions on the total quantity, quality, and cost of food are difficult to predict. (See page ___.)

74g. Current projections of the effects of climate change on agriculture are limited because of uncertainties in predicting local temperature and precipitation patterns using global climate models.

and because of the need for improved research studies using controlled atmospheres, statistical regression models, dynamic crop models and integrated modeling approaches. (See page ___.)

75. <u>WATER RESOURCE SYSTEMS HAVE UNDERGONE IMPORTANT CHANGES AS THE EARTH'S CLIMATE HAS SHIFTED IN THE PAST. CURRENT ANALYSES SUGGEST AN INTENSIFIED HYDROLOGIC CYCLE, IF CLIMATE CHANGE OCCURS AS PREDICTED</u>.

75a. There is evidence that climate change since the last ice age (18,000 years B.P.) has significantly altered the location of lakes -- although the extent of present day lakes is broadly comparable with 18,000 years B.P. For example, there is evidence indicating the existence of many tropical lakes and swamps in the Sahara, Arabian, and Thor Deserts around 9,000 to 8,000 years B.P. (See page ___.)

75b. The inextricable linkages between the water cycle and climate ensure that potential future climate change will significantly alter hydrologic processes throughout the world. All natural hydrologic processes--precipitation, infiltration, storage and movement of soil moisture, surface and subsurface runoff, recharge of groundwater, and evapotranspiration--will be affected if climate changes. (See page ___.)

75c. As a result of changes in key hydrologic variables such as precipitation, evaporation, soil moisture, and runoff, climate change is expected to have significant effects on water availability. Early hydrologic impact studies provide evidence that relatively small changes in precipitation and evaporation patterns might result in significant, perhaps critical, changes in water availability. For many aspects of water resources, including human consumption, agricultural water supply, flooding and drought management, groundwater use and recharge, and reservoir design and operation, these hydrologic changes will have serious implications. (See page ___.)

75d. Despite significant differences among climate change scenarios, a consistent finding among hydrologic impact studies is the prediction of a reduction in summer soil moisture and changes in the timing and magnitude of runoff. Winter runoff is expected to increase and summer to decrease. These results appear to be robust across a range of climate change scenarios. (See page __.)

75e. Future directions for research and analyses suggest that improved estimates of climate variables are needed from large-scale climate models; innovative techniques are needed for regional assessments, increased numbers of assessments are necessary to broaden our knowledge of effects on different users; and increased analyses of the impacts of changes in water resources on the economy and society are necessary. (See page ___.)

76. WEATHER IS CLOSELY ASSOCIATED WITH MORBIDITY AND MORTALITY RATES IN OUR SOCIETY.

76a. Weather has a profound effect on human health and well being. It has been demonstrated that weather is associated with changes in birth rates, outbreaks of pneumonia, influenza, and bronchitis, and related to other morbidity effects, and is linked to pollen concentrations and high pollution levels. (See page ___.)

76b. Large increases in mortality have occurred during previous heat and cold waves. It is estimated that 1,327 fatalities occurred in the United States as a result of the 1980 heat wave, and Missouri alone accounted for over 25 percent of that total. (See page ___.)

76c. Hot weather extremes appear to have a more substantial impact on mortality than cold wave episodes. (See page ___.)

76d. Threshold temperatures, which represent maximum and minimum temperatures associated with increases in total mortality, have been determined for various cities. These threshold temperatures vary regionally; for example, the threshold temperature for winter mortality in mild southern cities such as Atlanta is 0°C and for more northerly cities such as Philadelphia, threshold temperature is -5°C. (See page ___.)

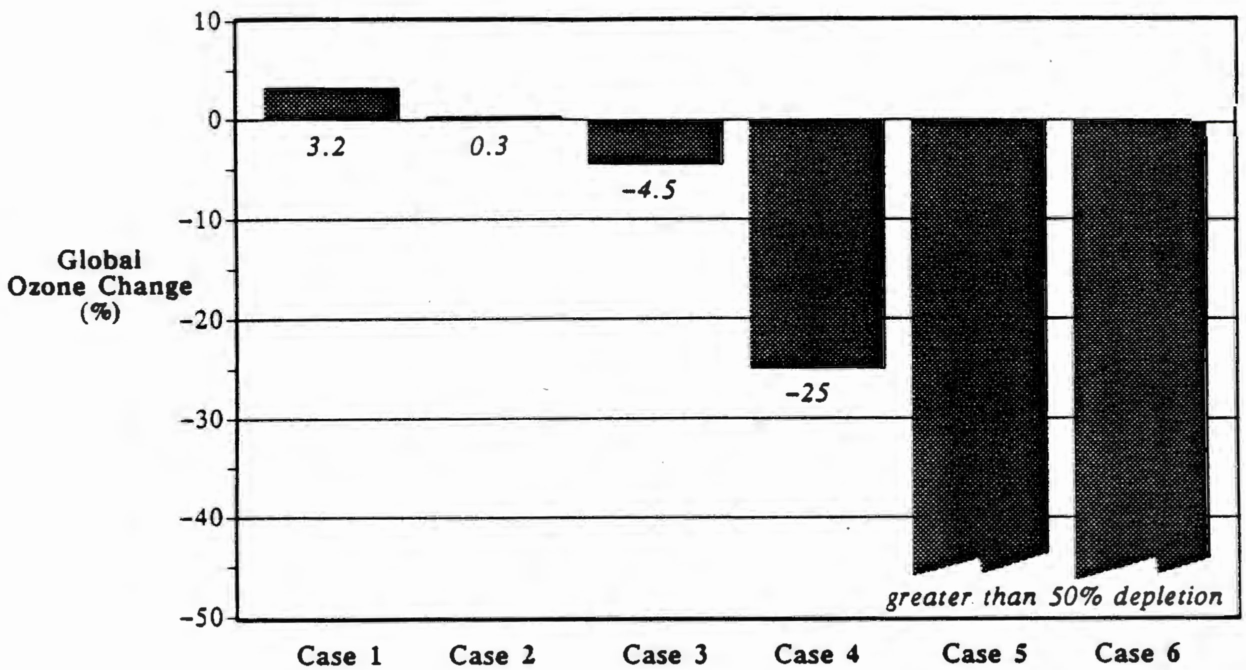
76e. If future global warming induced by increased concentrations of trace gases does occur, it has the potential to affect human mortality significantly. In one study, total summertime mortality in New York City was estimated to increase by over 3,200 deaths per year for a 7°F trace-gas-induced warming without acclimatization. If New Yorkers fully acclimatize, the number of additional deaths are estimated to be no different than today. It is hypothesized that if climate warming occurs, some additional deaths are likely to occur because economic conditions and the basic infrastructure of the city will prohibit full acclimatization even if behavior changes. (See page ___.)

77. MODIFICATION OF THE TRACE GAS COMPOSITION OF THE ATMOSPHERE CAN BE EXPECTED TO ALTER COLUMN OZONE ABUNDANCE

77a. The range of global average total column ozone change predicted for the year 2075 based on a parameterized representation of a one-dimensional model could vary from as high as over 50 percent depletion for a case where global CFC use grows at an average annual rate of 2.8 percent from 1985 to 2100 (5.0 percent per year from 1985 to 2050, followed by no growth through 2100), to increased abundance of ozone of approximately 3 percent for a case where global CFC use declines to 20 percent of its 1985 value by 2010. Exhibit ES-1 displays the global ozone change estimates for these two scenarios, as well as estimates for four scenarios in between; the six cases examined include:

EXHIBIT ES-1

ESTIMATES OF GLOBAL OZONE DEPLETION IN 2075
FOR SIX CASES OF CFC USE



Using a parameterized representation of a one-dimensional model, the potential change in ozone was evaluated for six cases: Case 1: global CFC use declines to 20 percent of current levels by 2010, and remains constant thereafter; Case 2: no growth in CFC use from current levels; Case 3: 0.7 percent annual average growth in CFC use from 1985 to 2100 (1.2 percent growth from 1985 to 2050, followed by no growth through 2100); Case 4: 1.4 percent annual average growth in CFC use from 1985 to 2100 (2.5 percent growth from 1985 to 2050, followed by no growth through 2100); Case 5: 2.1 percent annual average growth in CFC use from 1985 to 2100 (3.8 percent growth from 1985 to 2050, followed by no growth through 2100); Case 6: 2.8 percent annual average growth in CFC use from 1985 to 2100 (5.0 percent growth from 1985 to 2050, followed by no growth through 2100). The trace gas concentration assumptions used in these six cases are: CO_2: NAS 50th percentile; CH_4: 0.017 ppm per year (approximately 1 percent of current CH_4 concentration); and N_2O: 0.20 percent per year.

- Case 1: CFC use declines to 20 percent of its 1985 value by 2010, and remains constant thereafter, yielding approximately 3.0 percent increased ozone abundance by 2075;

- Case 2: no growth in CFC use from 1985 to 2100, yielding approximately 0.3 percent increased ozone abundance by 2075;

- Case 3: 0.7 percent annual average growth in CFC use from 1985 to 2100 (1.2 percent growth from 1985 to 2050, followed by no growth through 2100), yielding approximately 4.5 percent depletion by 2075;

- Case 4: 1.4 percent annual average growth in CFC use from 1985 to 2100 (2.5 percent growth from 1985 to 2050, followed by no growth through 2100), yielding approximately 25 percent depletion by 2075;

- Case 5: 2.1 percent annual average growth in CFC use from 1985 to 2100 (3.8 percent growth from 1985 to 2050, followed by no growth through 2100), yielding over 50 percent depletion by 2075;

- Case 6: 2.8 percent annual average growth in CFC use from 1985 to 2100 (5.0 percent growth from 1985 to 2050, followed by no growth through 2100), yielding over 50 percent depletion by 2075.

The trace gas concentration assumptions used in these six cases are: CO_2 -- NAS 50th percentile; CH_4 -- 0.017 ppm per year (approximately 1 percent of current CH_4 concentration); and N_2O -- 0.20 percent per year. (See page ____.)

77b. Current data are not sufficient for distinguishing whether CH_4 concentrations are likely to increase in a linear manner (e.g, at 0.017 ppm per year, or approximately 1 percent of current concentrations) or in a compound manner (e.g., at 1 percent per year, compounded annually). The sensitivity of the ozone change estimates in 2075 was evaluated for the following six assumptions regarding future CH_4 concentrations:

- M1: linear growth of 0.017 ppm per year (approximately 1 percent of current concentrations;

- M2: compound annual growth of 1 percent;

- M3: linear growth at 0.01275 ppm per year (75 percent of the 0.017 ppm growth);

- M4: linear growth at 0.02125 ppm per year (125 percent of the 0.017 ppm growth);

- M5: compound annual growth of 1 percent from 1985 to 2010, followed by constant concentrations at 2.23 ppm; and

- M6: compound annual growth of 1 percent from 1985 to 2020, growing to 1.5 percent compound annual growth by 2050 and thereafter.

For Case 4 of future CFC use, the estimate of ozone depletion by 2075 ranges from about 14 percent (M6) to 30 percent (M5) across these six CH_4 assumptions evaluated. For Case 2 of future CFC use, the range is from about 4.8 percent increase in ozone abundance (M6) to 2.0 percent depletion (M5). Exhibit ES-2 displays the results for the six CH_4 assumptions (M1 through M6) for Case 2 and Case 4. For Case 6, estimated ozone depletion exceeds 50 percent by 2075 under all six CH_4 assumptions (and is consequently not displayed in Exhibit ES-2). As shown in the exhibit, the difference between the 1 percent linear (0.017 ppm per year) and 1 percent compounded assumptions (M1 and M2) is approximately 6 percent depletion in Case 4 and approximately 2.5 percent depletion in Case 2. This sensitivity of the ozone depletion estimates to the assumption about linear versus compound growth of CH_4 concentrations is much larger than the sensitivity to the range of assumptions examined regarding future CO_2 concentrations (from the 25th to the 75th percentile NAS estimates) and regarding future N_2O concentrations (from 0.15 percent annual compound growth to 0.25 percent annual compound growth). (See page ____.)

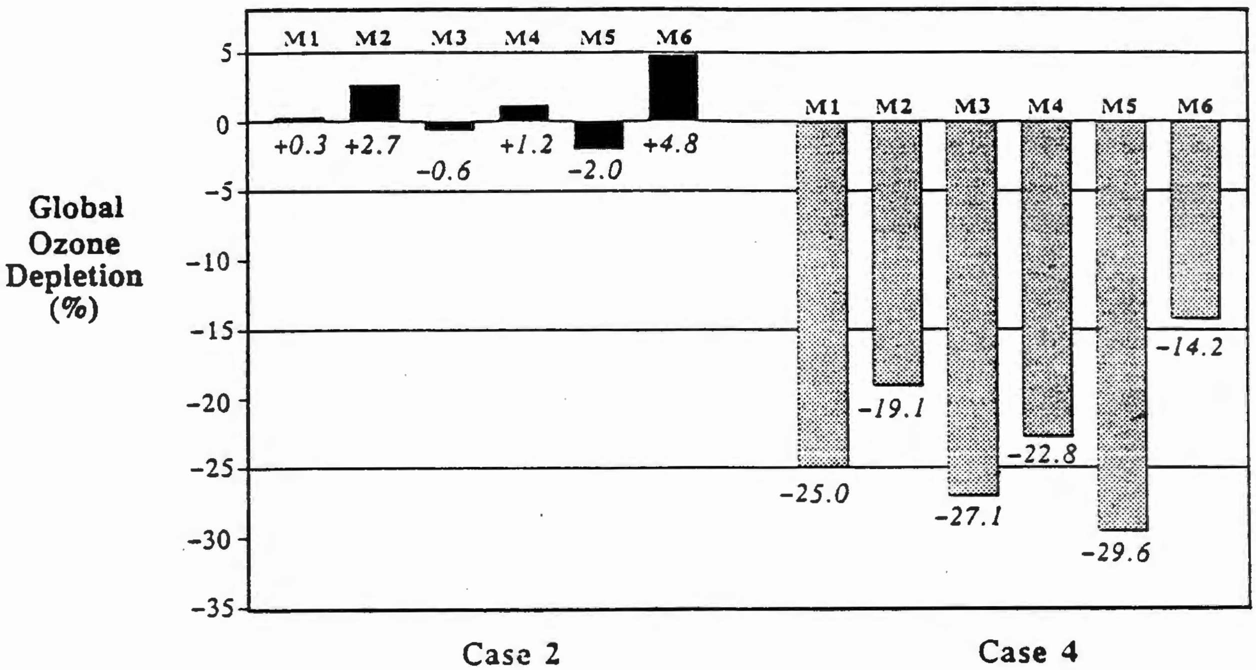
78. TWO-DIMENSIONAL (2-D) MODELS PREDICT GREATER AVERAGE GLOBAL DEPLETION THAN ONE-DIMENSIONAL (1-D) MODELS. 2-D MODELS ALSO PREDICT THAT OZONE DEPLETION WILL EXCEED THE GLOBAL AVERAGE AT HIGH LATITUDES.

78a. For a case of 3 percent annual growth in emissions of CFCs, no emissions of Halons, and increases in trace gases of: CO_2 -- approximately 0.6 percent per year; CH_4 -- 1 percent per year; and N_2O -- 0.25 percent per year, a 2-D model estimates approximately 5.4 percent global average depletion by 2030. For the same scenario of emissions and trace gas concentrations, the parameterized representation of a 1-D model estimates only 3.0 percent depletion by 2030. (See page ___.)

78b. For this same case of emissions and trace gas concentrations, the 2-D model estimates of ozone depletion in 2030 at high latitudes are approximately: 60°N -- 8.7 percent; and 50°N -- 7.0 percent. (See page ___.)

EXHIBIT ES-2

ESTIMATES OF GLOBAL OZONE DEPLETION IN 2075
FOR SIX METHANE CONCENTRATION ASSUMPTIONS
AND TWO CASES OF FUTURE CFC USE



Using a parameterized representation of a one-dimensional model, the potential change in ozone was evaluated for six assumptions about future methane concentration: M1: linear growth of 0.017 ppm per year (approximately 1 percent of current concentrations); M2: compound annual growth of 1 percent, M3: linear growth at 0.01275 ppm per year (75 percent of the 0.017 ppm growth); M4: linear growth at 0.02125 ppm per year (125 percent of the 0.017 ppm growth); M5: compound annual growth of 1 percent from 1985 to 2010, followed by constant concentrations at 2.23 ppm; and M6: compound annual growth of 1 percent from 1985 to 2020, growing to 1.5 percent compound annual growth by 2050 and thereafter.

The two cases of future CFC use examined are: Case 2: no growth in CFC use 1985 to 2100; and Case 4: 1.4 percent annual average growth in CFC use from 1985 to 2100 (2.5 percent growth from 1985 to 2050, followed by no growth thereafter). The other trace gas assumptions used in these cases are: CO2: NAS 50th percentile; and N2O: 0.20 percent growth per year.

79. <u>MODIFICATION OF TRACE GAS COMPOSITION OF THE ATMOSPHERE CAN BE EXPECTED TO CHANGE THE NUMBER OF SKIN CANCER CASES AND MORTALITIES OF PEOPLE CURRENTLY ALIVE OR PROJECTED TO BE BORN THROUGH THE YEAR 2075 AND BEYOND. FOR CASES OF HIGH GROWTH OF CFCs AND HALONS, THERE WILL BE SIGNIFICANT CANCER INCREASES. FOR THE CASE WHERE CFCs AND HALONS ARE EVENTUALLY PHASED OUT, SKIN CANCER INCIDENCE AND MORTALITY CAN BE EXPECTED TO DECREASE</u>.

79a. Based on estimates of ozone change from a parameterized representation of a 1-D model, the increase in the number of cases of skin cancer among people alive today and born through 2075 may exceed 200 million for the highest emission case examined (Case 6: 2.8 percent annual average growth in CFC use from 1985 to 2100 (5.0 percent growth from 1985 to 2050, followed by no growth through 2100)). About 80 percent of these cases would be expected to occur after 2075. For the lowest emission case examined (Case 1: an 80 percent reduction in CFC use by 2010), a decrease in cancer cases on the order of 4.5 million is estimated. The overwhelming majority (over 95 percent) of the increases and decreases in skin cancer cases estimated for this wide range of emissions scenarios is associated with basal and squamous cell cancers. Mortality impacts are on the order of 1.5 to 2.0 percent of the changes in the numbers of cases, with squamous cell cancers producing the largest mortality impact due to its sensitivity to UV-B increases. The estimated impacts are primarily associated with people born in the future. People alive today account for less than 5 percent of estimated increased cases, and people born between 1985 and 2030 account for about 20 to 30 percent. The remainder of the estimated impacts are accounted for by people born between 2030 and 2075. (See page ___.)

79b. The estimates of increased incidence vary on the order of 10 to 15 percent for the range of action spectra examined . (See page ___.)

79c. Statistical uncertainty regarding estimated dose-response coefficients influences the estimates of impacts on the order of plus and minus 50 percent (reflecting plus and minus one standard error of the estimates of the coefficients). Additional uncertainties exist, some of which cannot be quantified. (See page ___.)

80. <u>MODIFICATION OF THE TRACE GAS COMPOSITION OF THE ATMOSPHERE CAN BE EXPECTED TO INCREASE THE NUMBER OF CATARACTS</u>.

80a. Based on estimates of ozone change from a parameterized representation of a 1-D model, the increase in the number of cases of cataracts among people alive today and born through 2075 may exceed 50 million for the highest emission case examined (Case 6: 2.8 percent annual average growth in CFC use from 1985 to 2100 (5.0 percent growth from 1985 to 2050, followed by no growth through 2100)). About 80 percent of these cases would be expected to occur after 2075. For the lowest emission case examined (Case 1: an 80 percent reduction in CFC use by 2010), a decrease in cataracts on the order of 2 million is estimated. The estimated impacts are primarily associated with people born in the future. People alive today account for about 5 to 10 percent of estimated increased cases, and people born between 1985 and 2030 accounted for about 30 percent. The remainder of the impacts are accounted for by people born between 2030 and 2075. (See page ___.)

80b. The estimates of increased incidence vary on the order of 10 to 15 percent for the range of action spectra examined. (See page ___.)

80c. Statistical uncertainty regarding estimated dose-response coefficients influences the estimates of impacts on the order of plus and minus 50 percent (reflecting plus and minus one standard error of the estimates of the coefficients). Additional uncertainties exist, some of which cannot be quantified. (See page ___.)

81. MODIFICATION OF THE TRACE GAS COMPOSITION OF THE EARTH CAN BE EXPECTED TO RAISE THE GLOBAL EQUILIBRIUM AND ACTUAL TEMPERATURE OF THE EARTH.

81a. The equilibrium temperature increase by the year 2075 estimated using a one-dimensional model varies significantly across the six cases of CFC use examined (see above). For Case 6, in which CFC use grows at an average annual rate of 2.8 percent from 1985 to 2100 (5% before 2050; 0% thereafter), equilibrium temperatures could rise about 11.5°C from temperatures observed in 1985. For Case 1, in which CFC use decreases by 80 percent by 2010, equilibrium temperatures could rise about 2°C. The climate sensitivity to doubled CO_2 is assumed to be 3°C for these estimates, and the growth in other trace gas concentrations used was: CO_2: NAS 50th percentile; CH_4: 0.017 ppm per year; and N_2O: 0.20 percent per year. Higher rates of growth in other trace gases result in larger estimates of warming. The National Academy of Sciences has suggested that the uncertainty associated with these types of estimates is plus and minus 50 percent. (See page ___.)

81b. Sea level would be expected to rise with this warming. By 2075, thermal expansion and alpine melting may contribute between 35 cm and 80 cm under the above assumptions. Glacial contributions are particularly uncertain (particularly from Antarctic glaciers) and may be between 20 cm and 110 cm by 2075, for a total rise of 55 cm to 190 cm. (See page ___.)

82. WHILE QUANTITATIVE ESTIMATES OF AQUATIC, CROP, GROUND-BASED OZONE, AND SEA LEVEL RISE DAMAGE CANNOT BE MADE AT THIS TIME, CASE STUDY RESULTS INDICATE THAT SIGNIFICANT INCREASES IN GROUND-BASED OZONE, LOSS OF AQUATIC LIFE, SEA LEVEL RISE DAMAGE, AND LOSS OF CROP YIELD ARE POSSIBLE.

82a. According to a single study of possible changes in tropospheric ozone in urban areas, a 33 percent ozone depletion could cause peak ozone values to rise about 50 percent in Nashville, about 9 percent in Los Angeles, and about 33 percent in Philadelphia. Three of the 6 cases of CFC use examined could result in ozone depletion of this order of magnitude. Care should be taken in interpreting these results, however, and additional studies are needed to assess these results. (See page ___.)

82b. The results of a case study suggest that northern anchovies could be harmed by ozone depletion. Laboratory studies indicate that under some conditions, as small as a 10 percent increase in UV-B could have an adverse influence on anchovy mortality. A 30 percent increase in UV-B could increase mortality by zero to 10 percent, and a 60 percent increase in UV-B could increase mortality by 11 to 25 percent. Three of the 6 cases of CFC use examined could result in UV-B increases of this order of magnitude. Care should be taken in interpreting these results, however, and additional studies are needed to assess these results. (See page ___.)

82c. Field experiments on the Essex cultivar of soybeans indicate that a 25 percent ozone depletion could reduce yields by up to 25 percent. Actual damages might be somewhat lower if UV-resistant cultivars that exist become preferred. Greenhouse experiments indicate that 2 out of 3 cultivar tested are sensitive to UV. Additional study is required to better assess the potential impacts of UV-B on crops. (See page ____.)

82d. Based on a case study of the economic impacts of sea level use, the potential economic impact of a 55 cm to 190 cm rise by 2075 on the two U.S cities studied is on the order of $400 million to $3.7 billion (present value, 1980 dollars). The magnitude of impact is sensitive to assumptions regarding whether and how people prepare for future sea level rise. Additional studies are required to confirm the magnitude of these estimates, and to develop estimates for the total U.S. impact. (See page ____.)