AN ASSESSMENT OF THE RISKS OF STRATOSPHERIC MODIFICATION

Volume I: EXECUTIVE SUMMARY

Submission to the

Science Advisory Board
U.S. Environmental Protection Agency

By

Office of Air and Radiation
U.S. Environmental Protection Agency

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Comments should be addressed to:

John S. Hoffman
U.S. Environmental Protection Agency, PM 221
401 M Street, S.W.
Washington, D.C. 20460
USA

The following report is being submitted to the Science Advisory Board and to the public for review and comment. Until the Science Advisory Board review has been completed and the document is revised, this assessment does not represent EPA's official position on the risks associated with stratospheric modification. This report has been written as part of the activities of the EPA's congressionally-established Science Advisory Board, a public group providing extramural advice on scientific issues. The Board is structured to provide a balanced independent expert assessment of scientific issues it reviews, and hence, the contents of this draft report do not necessarily represent the views and policies of the EPA nor of other agencies in the Executive Branch of the Federal Government. Until the final report is available, EPA requests that none of the information contained in this draft be cited or quoted. Written comments can be sent to the Science Advisory Board and would be appreciated by November 14, 1986. Public comments should be submitted to John Hoffman by December 15, 1986.

*** DRAFT FINAL ***

SUMMARY

Rising concentrations of chlorofluorocarbons (CFCs) and Halons have the potential to deplete stratospheric ozone and to allow additional quantities of the biologically damaging part of the ultraviolet radiation spectrum (UV-B) to penetrate to the earth's surface, where it would harm public health and the environment. While considerable scientific uncertainties remain, substantial advances have taken place in understanding of this issue since the development of the theory linking CFCs to ozone depletion in 1974.

Over the past decade, non-aerosol CFC use has risen as the global economy has grown. A variety of studies indicate that the long-term growth of CFCs, in the absence of additional regulation, is likely to be between 1% and 4% annually.

Atmospheric concentrations of other trace gases (e.g., carbon dioxide, methane, and nitrous oxide) are also growing. The sources of carbon dioxide increases can be linked primarily to expanded use of fossil fuels, and secondarily to deforestation. In contrast, far less is understood about the sources and sinks of methane and nitrous oxide. Unlike CFCs and halons, these gases either add to the amount of ozone or reduce the rate of depletion. Like CFCs, these gases are greenhouse gases that are predicted to increase global temperatures and change global climate. Since future trends in emissions of these gases are important factors in determining ozone modification and climate change, assumptions about their growth must be carefully considered.

Models of stratospheric chemistry and physics are used to predict future changes in the ozone layer. While these models fail to accurately reflect all the complex forces which interact in the atmosphere to create and destroy ozone, nonetheless, they represent the most advanced tools for understanding possible changes in the ozone layer that could be related to future scenarios of trace gases. One-dimensional models predict that average global ozone will decline for all scenarios in which CFCs grow. Two-dimensional models analyze ozone depletion for seasons and latitudes. These models predict depletion at higher latitudes even if CFC use is reduced to 1980 levels and other trace gases continue to grow at recent rates.

Model estimates of total column depletion are sensitive to the continued release of greenhouse gases that counter ozone loss. If an assumption is made that emissions of these gases are eventually limited in order to reduce the magnitude of future global warming, the depletion expected from any scenario of CFC emissions would be larger.

Because the current models oversimplify or fail to include processes that occur in the atmosphere, a critical question relates to how useful they are as a predictive tool. One method of testing their validity is to compare their predictions against observations of the atmosphere. Models currently closely reproduce most atmospheric measurements, but fail to accurately reproduce some, including ozone in the upper stratosphere and the rapid depletion of ozone in Antarctica in the last six years. These inconsistencies lower our

confidence in models, making us less certain that they are not underpredicting or overpredicting depletion. At this time, however, analysis of Antarctic data has not proceeded far enough to justify abandoning current models as the best tools for risk assessment.

Many inputs to these models are based on laboratory measurements. Uncertainty about the accuracy of these measurements is one potential area responsible for the inadequacies of current model predictions. Analyses of the implications of this class of uncertainties indicate that if CFCs grow, there is only a small chance of no depletion even if laboratory measurements change within the ranges tested. The chances of a depletion significantly greater than the average predicted appears larger than the chances of one significantly smaller.

If depletion in column ozone takes place, increases will occur in basal and squamous skin cancer cases and are considered likely for melanoma skin cancer. Deaths from these cancers would also increase. If depletion occurs, additional cataract cases could be expected, along with increased suppression of the immune system. The effect of this immune suppression on infectious diseases like herpes and leishmaniasis would be to reduce the body's capacity to prevent spread or outbreaks. Little is known about effects on other cutaneous infectious diseases.

While quantitative assessments of the risk to crops and terrestial and aquatic ecosystems from higher UV-B associated with depletion are not yet possible, evidence appears to indicate that significant risks exist. While some cultivars of plants are less susceptible and photorepair mechanisms may reduce losses, field tests to date have shown damaging effects on yield. In the case of aquatic organisms, experimental design is far more complicated. Initial studies suggest that some species are damaged more than others. The net effect on productivity and any implications for the aquatic food chain cannot yet be determined.

If ozone depletes, polymers would be expected to degrade more quickly, although quantitative estimates are available for only one polymer. Finally, based on one study, depletion is predicted to increase both tropospheric ozone (i.e., smog) in urban areas and the production of hydrogen peroxide (an acid rain precursor).

Increases in CFCs and other trace gases and resulting stratospheric modification all are expected to contribute to global warming and climate change. According to the National Academy of Science the magnitude of future warming is very uncertain. The currently accepted range is 3°C $\pm$ 1.5°C for doubled CO_2 or its equivalent in radiative forcings from other gases. Cloud response to warming is the major uncertainty with regard to the magnitude of warming. The timing of the warming is also uncertain. Oceanic heat absorption is the major question with regard to the speed which the world's temperature can expect to increase.

Global warming is likely to cause thermal expansion of the oceans and alpine melting, raising sea level. The contribution of ice deglaciation to sea level rise is much more uncertain.

Sea level rise can be expected to innundate land, especially wetlands, erode recreational beaches, and cause increased flooding and saltwater intrusion into freshwater areas. River delta areas are expected to be most at risk. Case studies in two U.S. cities indicate that sea level rise can be expected to cause significant economic damage, some of which could be mitigated by anticipatory actions.

The climate change (e.g., shifts in rainfall, storm tracks, etc.) that would be associated with global warming is more difficult to predict than sea level rise, as are the effects of that climate change. Nevertheless, studies suggest that forests, water resources, agriculture, and health will all be affected.

An integrated analysis of the likely emissions, atmospheric response, and effects (based on a one-dimensional model) indicates that under the central case assumptions the U.S. can expect 40 million additional skin cancer cases and 800,000 deaths for people alive today and those born during the next 88 years if there is no further action taken to limit CFCs. Two-dimensional models, because they include estimates of depletion by latitude, may be more suitable for estimating impacts. Preliminary analysis using these models suggests that the effects could be twice as high. In addition, estimates of ozone depletion would be much higher if greenhouse gases are eventually limited, approximately doubling for a case which assumed that greenhouse gases are limited in order to hold warming to 3°C (assuming 3°C for doubled CO_2; the actual limitation imposed by such a reduction in greenhouse gases could be 1.5°C or 4.5°C, based on the NAS range).

Integrated analyses show that estimates of damages are sensitive to the rate of CFC and other trace gas growth. Quantitative estimates of damage are also sensitive to assumptions underlying relationships between exposure and impact in each of the effects area.

A further underlying uncertainty exists about risk estimates -- no experiments can be conducted with the earth to validate these models. Thus, there is no guarantee that models are not under or overpredicting the magnitude of the risks.

SUMMARY OF FINDINGS

1. IN THE ABSENCE OF REGULATION, ATMOSPHERIC CONCENTRATIONS OF POTENTIAL OZONE-DEPLETING CHEMICALS ARE LIKELY TO INCREASE WITH WORLD ECONOMIC GROWTH.

   1a. Estimates of chlorofluorocarbons (CFCs) 11 and 12 based on economic analysis indicate that average long-term growth is likely to be 2.5% per year; growth of CFC 113 and 22 is expected to be higher.

   1b. While significant uncertainty surrounds long-term growth estimates, a variety of studies indicate that growth is unlikely to be negative nor greater than 5%; several studies indicate that a long-term growth rate between 1.2% and 3.8% is more likely.

   1c. Halon 1211 and 1301, two brominated fire extinguishants, may grow fast enough to become significant contributers to ozone depletion.

2. CONCENTRATIONS OF OTHER TRACE SPECIES (CARBON DIOXIDE, METHANE, NITROUS OXIDE) THAT COUNTER OZONE DEPLETION ARE ASSUMED TO INCREASE AT APPROXIMATELY THE SAME RATE AS IN RECENT YEARS. THESE TRACE SPECIES ARE ALSO GREENHOUSE GASES THAT WILL ADD TO GLOBAL WARMING.

   2a. A variety of studies based on future fossil fuel consumption have estimated carbon dioxide (CO_2) growth. Assuming moderate economic growth and technological change, CO_2 emissions were predicted to grow at 0.6% annually.

   2b. Recent measurements of nitrous oxide (N_2O) show growth of 0.25% per year. Continuation of the trend was used in the central case.

   2c. Recent measurements of methane (CH_4) show 1.0% per year increase. Continuation of the trend was assumed in the central case.

   2d. Significant uncertainty surrounds all these trends. Because little is understood about the sources and sinks of methane, and it has a relatively short atmospheric lifetime, assumptions about future trends of this gas are particularly uncertain.

   2e. The standard assumption the modeling community has used in developing scenarios has been that long-term projections of trace gases that counter ozone depletion will not be limited by future decisionmakers in order to reduce the magnitude of global warming.

3. MODELS OF THE STRATOSPHERE PREDICT DEPLETION FOR SCENARIOS IN WHICH CFCS AND OTHER TRACE GASES CONTINUE TO GROW. MODELS PREDICT DEPLETION AT HIGHER LATITUDES EVEN FOR SCENARIOS IN WHICH THE EMISSIONS OF POTENTIAL OZONE DEPLETERS ARE LOWER THAN TODAY'S EMISSIONS.

   3a. While different models produce slightly different changes in ozone for the same scenario, they generally provide roughly consistent estimates.

3b. Estimated changes in ozone levels are dependent on assumptions about trace gas growth. For example, if CFCs do not grow and other trace gases continue to increase, greater amounts of ozone are likely.

3c. Based on a two-dimensional model, depletion with 3% growth of CFCs and standard assumptions for gases that counter depletion is predicted to be 7% by 2030 at 50°N.

4. PREDICTED OZONE DEPLETION IS SIGNIFICANTLY GREATER FOR SCENARIOS IN WHICH GROWTH IN CO2, N2O, AND CH4 IS NOT ASSUMED TO CONTINUE UNABATED FOR THE NEXT CENTURY.

4a. Depletion estimates would be doubled if greenhouse warming were ultimately limited to 3°C (the limitation assumes 3°C temperature sensitivity for double CO_2; the actual limit could vary by $\pm$50%).

4b. Depletion would be even greater for a more stringent temperature limit.

5. A NUMBER OF INCONSISTENCIES BETWEEN OBSERVATIONS AND PREDICTIONS LOWERS OUR CONFIDENCE THAT MODELS ARE NOT UNDER OR OVER PREDICTING DEPLETION. HOWEVER, CURRENT MODELS DO ACCURATELY REPRESENT MANY ELEMENTS OF THE ATMOSPHERE AND STILL APPEAR TO BE THE MOST RELIABLE METHOD OF ESTIMATING THE RISKS ASSOCIATED WITH FUTURE SCENARIOS OF TRACE GAS EMISSIONS.

5a. Models reproduce most observations of the current atmosphere relatively well, supporting the belief they can usefully be used as tools to predict the future.

5b. Discrepancies exist between some predictions and both observations and measurements of various species in the current atmosphere thus lowering our confidence that the models will not under or over predict depletion.

5c. From 1970-83 models have predicted depletion in upper layers of the stratosphere. This is consistent with actual measurements at 40 km.

5d. Analyses of the uncertainties of laboratory measurements used as one class of inputs to atmospheric models indicate that if chlorine grows, depletion is likely. The analyses also demonstrate that a depletion significantly larger than that yielded by the standard inputs is more likely than a depletion that is significantly lower.

6. THE FAILURE OF MODELS TO PREDICT THE ANTARCTIC OZONE DEPLETION RAISES SERIOUS QUESTIONS ABOUT MODEL RELIABILITY. HOWEVER, UNTIL A BETTER UNDERSTANDING AND ANALYSIS OF THIS PHENOMENON IS ACHIEVED, CURRENT MODELS ARE STILL THE MOST APPROPRIATE TOOLS FOR RISK ASSESSMENT.

6a. The seasonal Antarctic depletion has been verified by several different types of instruments; models with conventional chemistry cannot explain the Antarctic depletion.

6b. Several chemical and dynamical theories have been proposed to explain the seasonal Antarctic depletion. Current observations are insufficient to determine which, if any, are true or false.

6c. At this time, it is unclear whether the seasonal Antarctic depletion is a precursor to a general atmospheric phenomenon, will be an anomaly that remains in this unique and geographically isolated region, or will disappear altogether.

6d. Satellite measurements from Nimbus 7 appear to indicate a depletion in recent years in the Arctic. The scientific community has not analyzed this data sufficiently to reach a consensus on the validity of the data as its been interpreted, its meaning, or even to conclude it is not part of a cyclical trend. Until this data and its interpretation are verified, and causality is determined, it cannot be used as a basis for considering the risks from CFCs.

7. OZONE DEPLETION WILL CAUSE AN INCREASE IN SQUAMOUS AND BASAL SKIN CANCERS; A GREATER RISE WILL OCCUR IN SQUAMOUS SKIN CANCER.

7a. Squamous skin cancer can be anticipated to rise between 2 and 5 percent for each one percent depletion of ozone. Squamous skin cancer is generally more serious than basal cancer and proves fatal in a higher percentage of cases.

7b. Basal skin cancer can be anticipated to rise between 1 and 3 percent for each one percent depletion of ozone.

7c. Although only a very small percentage of cases of these skin cancers result in mortality, the large number of additional cases will aggregate to create a substantial increase in total number of skin cancers.

8. OZONE DEPLETION IS LIKELY TO CAUSE AN INCREASE IN MELANOMA SKIN CANCER, ALTHOUGH SOME UNCERTAINTY REMAINS ABOUT THIS CONCLUSION.

8a. Melanoma is a deadly form of skin cancer that currently kills 5,000 people in the United States a year.

8b. Although conclusive evidence does not yet exist, many factors suggest that UV-B radiation plays a substantial role in the incidence of melanoma skin cancer.

8c. Melanoma incidence is likely to rise between 1 and 2 percent for each one percent increase in ozone depletion.

8d. Melanoma mortality is likely to increase about 0.8 to 1.5 percent for each one percent increase in ozone depletion.

9. OZONE DEPLETION IS LIKELY TO SUPPRESS THE IMMUNE SYSTEM OF HUMANS.

9a. Laboratory evidence and case studies demonstrate that exposure to UV-B radiation has the effect of suppressing the immune system.

9b. Although quantitative estimates are impossible, depletion is likely to increase outbreaks of herpes and the severity of leishmaniasis.

9c. The impact of immune suppression on other infectious cutaneous diseases has not yet been studied.

10. OZONE DEPLETION IS LIKELY TO CAUSE AN INCREASE IN CATARACTS.

10a. Laboratory evidence and epidemiology studies have shown that exposure to UV-B radiation is one cause of cataracts.

10b. A 1% ozone depletion is likely to cause between a 0.3% to 0.6% increase in cataract cases.

10c. In the U.S., cataracts are treatable, but are still the third leading cause of blindness. In developing countries they are also a primary source of blindness.

11. OZONE DEPLETION IS LIKELY TO REDUCE CROP YIELD IN CERTAIN CULTIVARS, AND ALTER COMPETITION BETWEEN PLANTS. THE DIMENSIONS OF THE CHANGES ARE NOT YET QUANTIFIABLE.

11a. Information on the effects of increased UV-B exposure on plants is very limited. Few plants have been tested under natural conditions.

11b. Some cultivars appear to be more susceptible to UV-B than others. Inadequate information exists to determine why this occurs and if selective breeding could be an effective defense to mitigate damages from ozone depletion.

11c. Two out of three cultivars of soybeans tested were sensitive to enhanced UV-B. One cultivar that was tested extensively showed a yield loss of up to 25% for a 20% depletion.

11d. Field experiments show UV-B may affect competition between plant species. Ozone depletion, particularly in conjunction with other stresses, might alter ecosystems in ways not yet understood.

12. OZONE DEPLETION IS LIKELY TO ALTER AQUATIC ECOSYSTEMS AND POSSIBLY AFFECT THE AQUATIC FOOD CHAIN. THE DIMENSIONS OF THE POSSIBLE CHANGE ARE NOT YET QUANTIFIABLE.

12a. Limited experiments suggest that increased UV-B can alter the community composition of phytoplankton that form the base of the aquatic food web, can curtail the survival of zooplankton, and can shorten breeding seasons.

12b. Uncertainties in the lifecycles of these organisms prevents quantitative estimation of effects, although some data exist which suggest that relatively low thresholds of tolerance to increases in UV-B could affect commercially important species. However, movement to limit exposure, and turbulence or mixing may limit damage to organisms.

13. <u>OZONE DEPLETION WOULD DEGRADE POLYMERS, SHORTENING THEIR USEFUL LIFE. COUNTERMEASURES WOULD ADD COST AND POSSIBLY REDUCE PRODUCT QUALITY</u>.

13a. Current usage shows that UV-B damages physical and chemical properties of certain polymers.

13b. Stabilizers can be added to mitigate damage from increased UV-B, but at a price and possible loss in product quality.

13c. Uncertainty exists about effects of higher UV-B on polymers due to a lack of an adequate experimental data base relating UV-B dose to degradation.

13d. One study that examined the effects of UV-B on polyvinylchloride showed substantial losses from future ozone depletion.

14. <u>BY INCREASING UV-B, OZONE DEPLETION MAY INCREASE URBAN OZONE, A POLLUTANT REGULATED UNDER THE CLEAN AIR ACT. IT MAY ALSO INCREASE HYDROGEN PEROXIDE, AN ACID RAIN PRECURSOR</u>.

14a. The only study on this issue stated that increased UV-B could cause increases in ground-based ozone (i.e., smog). In addition, because the ozone formed earlier in the day, it would affect larger populations.

14b. It also showed that global warming could enhance the negative effect of enhanced UV-B on ground-based oxidants.

14c. The study also predicted that hydrogen peroxide production was extremely sensitive to increased UV-B.

14d. Continued studies on the effects of UV-B on ground-based oxidants and hydrogen peroxide formation are needed to validate this initial effort.

15. <u>INCREASES IN TRACE SPECIES THAT MODIFY OZONE ARE ALSO EXPECTED TO CAUSE A SIGNIFICANT GLOBAL WARMING</u>.

15a. The National Academy of Sciences estimated a warming or 3°C $\pm$ 1.5°C for doubled CO_2. This range is attributable to uncertainty as to whether changes in clouds will amplify or dampen global warming.

15b. The timing of the warming is expected to lag the emission of gases by 10 to 40 years. Uncertainty about the timing is due to a lack of knowledge about the rate of oceanic heat absorption.

15c. Changes in stratospheric water vapor would raise global temperatures. Changes in vertical structure of ozone would add to warming until depletion became large, at which point it would begin decreasing temperatures.

15d. Due to deficiencies in model representations of a variety of phenomena, regional characteristics of the climate change that would accompany the global warming are largely uncertain. In general, temperatures will increase the further one goes from the equator, the hydrological cycle will intensify, and areas of wetness and dryness will shift. Little else about climate changes can be stated with certainty.

16. <u>SEA LEVEL IS LIKELY TO RISE AS A RESULT OF GLOBAL WARMING. PREDICTIONS ARE UNCERTAIN, BUT SEVERAL STUDIES HAVE ESTIMATED A RANGE FROM 50 CM TO 200 CM BY 2100 IF GREENHOUSE GAS GROWTH IS NOT CURTAILED</u>.

16a. The primary cause of sea level rise will be thermal expansion and alpine ice melting. Only for the higher estimates will Antarctic deglaciation contribute significantly.

16b. Sea level rise can be expected to innudate and erode coastal land, to increase flooding, and to produce saltwater intrusion into freshwater areas.

16c. Wetlands and river deltas will be most adversely affected. By 2100 the U.S. could lose up to 50% to 80% of its coastal wetlands.

16d. Preliminary studies suggest adverse economic effects, which could be substantially reduced by anticipatory planning.

17. <u>GLOBAL WARMING CAN BE EXPECTED TO ALTER REGIONAL CLIMATES AND AFFECT MANY ASPECTS OF THE ENVIRONMENT</u>.

17a. Based on analyses of past climatic changes of roughly similar magnitude (but which occurred over far longer periods of time), forests will be altered significantly.

17b. Limited assessments suggest that important changes in farm productivity can be expected throughout the world.

17c. The location and design of water resource projects are likely to be altered by climate change.

17d. Human morbidity and mortality could be influenced. According to the one study on this issue, in the absence of full acclimatization (which is doubtful in built-up cities like New York) mortality from extreme temperatures is likely to increase.

18. FOR THE MOST LIKELY ASSUMPTIONS ABOUT EMISSIONS, ATMOSPHERIC RESPONSE, AND EFFECTS, SIGNIFICANT IMPACTS ARE EXPECTED FOR HUMAN HEALTH AND THE ENVIRONMENT. HOWEVER, MAJOR UNCERTAINTIES EXIST ABOUT EACH AREA. CONSEQUENTLY THE SENSITIVITY OF RISK ESTIMATES TO THOSE UNCERTAINTIES MUST BE EXAMINED. ESTIMATES OF RISKS IN THIS STUDY ASSUME NO ACTION IS TAKEN TO REDUCE DEPLETION.

18a. For the central case (2.5% CFC growth, 0.6% CO2 growth, and recent trends for other gases), an additional 40 million skin cancer cases and 800,000 deaths are projected for people alive today and those born in the next 88 years in the United States. An additional 12 million cataract cases could occur.

18b. The earth's equilibrium temperature would rise from 3°C to 9.5°C by 2075.

18c. Estimates of risk from ozone depletion are highly sensitive to the assumptions about growth in greenhouse gases that counter such depletion. Limiting equilibrium global warming to 3°C (assuming 3°C sensitivity for doubled CO2) would more than double the risks of ozone depletion from CFC and halon growth.

18d. Estimates of risks are highly sensitive to CFC and halon growth rates. If one assumes half the CFC growth rate of the standard case, that is 1.2% instead of 2.5%, estimated damage can be reduced by 90%. If one assumes a growth rate of 3.8%, estimated damages would increase 400%.

18e. Damage estimates are sensitive to the atmospheric model used. With two-dimensional models, estimates of all damages would approximately double.

18f. Uncertainties about dose-response relationships lead to changes in estimates of the number of cases by 35% for nonmelanoma and by as much as 60% for melanoma.

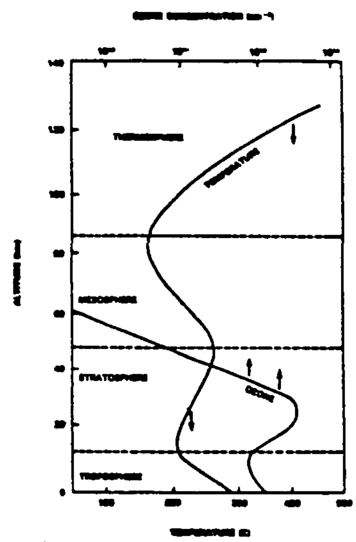
18g. Quantitative estimates of damages for other areas -- crops, aquatics, ground-based ozone, sea level rise, and polymers -- cannot yet be calculated.

INTRODUCTION

Moving from the surface of the earth towards space, the temperature falls until the stratosphere is reached at 10-15 kilometers above the earth's surface. At this point temperatures begin to rise (Exhibit 1). The stratosphere sustains unique conditions in which ozone (O3) is constantly produced and destroyed, providing an abundance that varies latitudinally, seasonally and annually around long-term means.

EXHIBIT 1

Temperature Profile and Ozone Distribution in the Atmosphere



Small quantities of chlorine, nitrogen, hydrogen, or bromine can combine in chemical reactions with ozone molecules to produce bimolecular oxygen (O2). These substances act as a catalyst. They are freed following a series of reactions and can repeatedly combine with ozone. Chlorofluorocarbons, methyl chloroform and carbon tetrachloride can carry chlorine to the stratosphere, halons can carry bromine, and nitrous oxide can carry nitrogen. The chlorine and bromine from chlorofluorocarbons and halons act as strong depleters of ozone. Nitrous oxide, in the face of growing chlorine, can interfere with the destruction of ozone by chlorine. Carbon dioxide cools the stratosphere, reducing the destruction rate of ozone. Methane creates ozone in the troposphere (which contains 10% of the column ozone) and interferes with ozone destruction in the stratosphere. It also increases stratospheric water vapor. All of these molecules are greenhouse gases. Exhibit 2 summarizes their atmospheric effects.

EXHIBIT 2

Stratospheric Perturbants and Their Effects

	Direct Effect on Global Temperature from Tropospheric Presence	Physical Effect on Stratosphere	Effect on Column Ozone
Carbon Dioxide	Increases[1]	Cools[2]	Increases ozone[3]
Methane	Increases[1]	Adds water vapor; hydrogen[4]	Increases ozone at some latitudes[5], interferes with depletion at high altitudes
Nitrous oxide	Increases[1]	Adds nitrogen[4]	Interferes with catalytic efficiency of chlorine[6]
Chlorofluorocarbons	Increases[1]	Adds chlorine[4]	Decreases ozone[4]
Other Trace Gases (methyl chloroform, carbon tetrachloride, halons)	Increases[1]	Adds catalytic species to stratosphere[4]	Decreases ozone[4]

[1] Ramanathan et al., 1985.

[2] Connell and Wuebbles, 1986.

[3] Isaksen, personal communication.

[4] National Academy of Sciences, 1984.

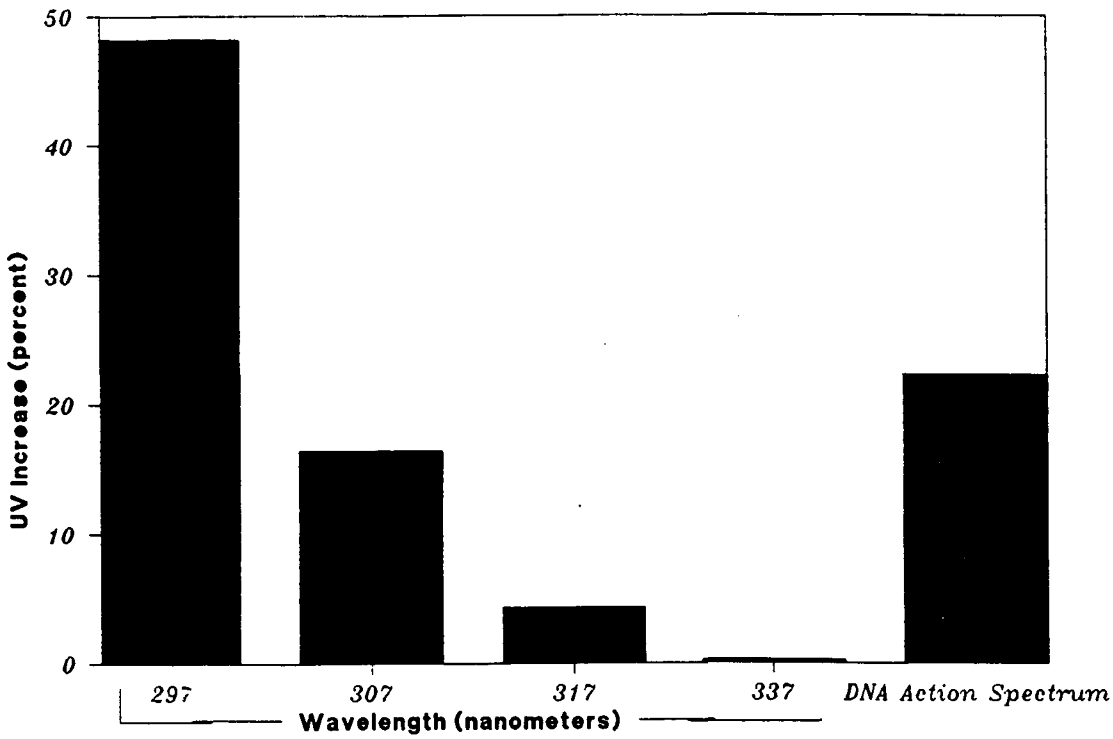
[5] Isaksen and Stordal, 1986.

[6] National Academy of Sciences (1984) notes the direct effect of N2O on column ozone. In the presence of high levels of chlorine, N2O may interfere with the catalytic cycle of chlorine, reducing net depletion (Stolarski, personal communication).

Depletion of ozone would allow more ultraviolet radiation to reach the earth's surface where it could harm human life, plants and aquatic organisms, and materials. Less ozone would allow for increased penetration of the biologically damaging, shorter, part of the ultraviolet radiation spectrum, generally referred to as UV-B radiation (Exhibit 3).

EXHIBIT 3

Percent Increase in UV-B Radiation for a 10% Depletion



Results for Washington,D.C., for clear skies in June.
Source:NASA UV model results

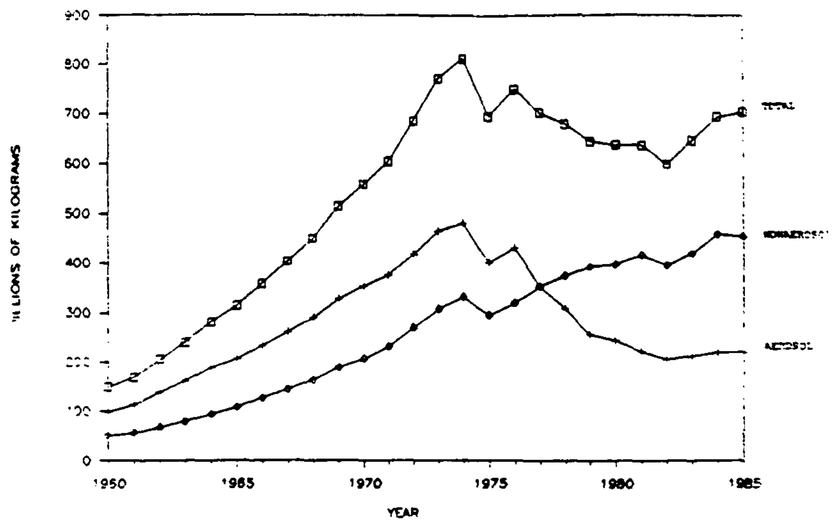
RISING CONCENTRATIONS OF TRACE SPECIES

Past emissions of CFC 11 and 12 have caused a rise in their atmospheric concentrations (Exhibit 4). These CFCs have been rising at 5% annually. Atmospheric measurements show that CFC 113 has grown at 10% annually, and Halon 1211 at 23% annually. Chlorofluorocarbons are used in foam blowing, refrigeration and air conditioning, as a solvent in electronics and metal industries, as aerosol propellants, and in a variety of specialty applications. Halons are used in many applications as a fire extinguishant.

EXHIBIT 4

Historical Production and Atmospheric Concentrations of CFC-11 and CFC-12

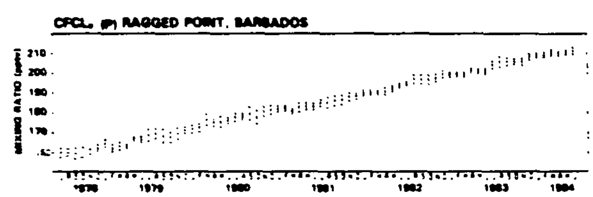
Historical Production of CFC-11 and CFC-12



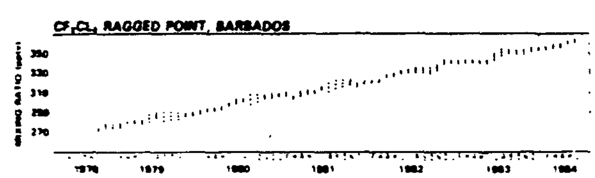
Total reported production of CFC-11 and CFC-12 increased rapidly throughout the 1960s and 1970s, reaching a maximum of 813 thousand metric tons in 1974. Aerosol applications declined since the mid-1970s, while nonaerosol applications continued to increase. (Note: aerosol/nonaerosol divisions prior to 1976 are estimates.)

Source: CMA (1986), "Production, Sales, and Calculated Release of CFC-11 and CFC-12 Through 1985,." Washington, D.C.

Measured Increases in Tropospheric Concentrations of CFC-11 and CFC-12



CFC-11



CFC-12

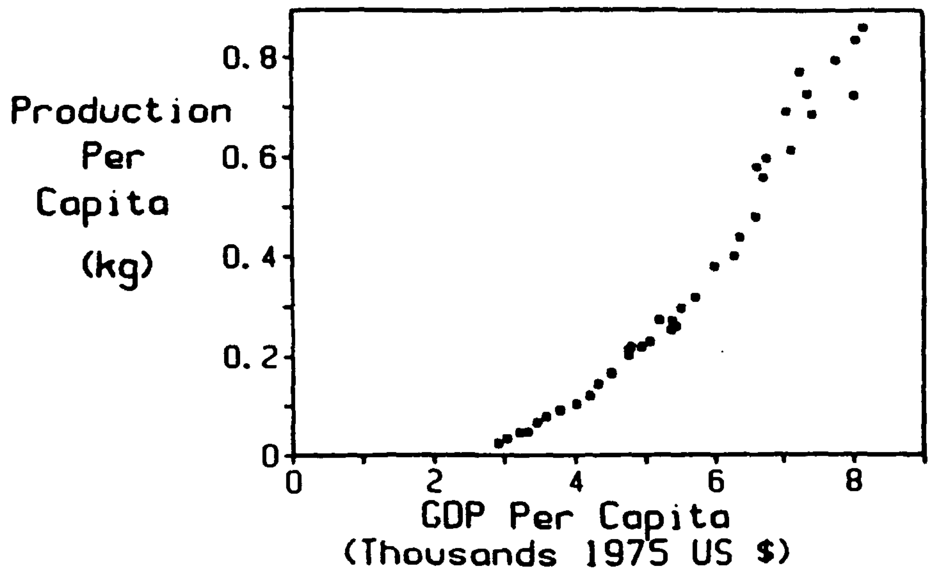
Average concentrations of CFC-11 and CFC-12 are increasing at approximately five percent per year. Data are from the Atmospheric Lifetime Experiment.

Source: World Meteorological Organization, 1986

Based on past trends, emissions of CFC 11 and 12 have closely tracked GNP, growing about twice as fast (Exhibit 5) since the early 1960s. CFC-113 has grown at an even faster pace.

EXHIBIT 5

Nonaerosol Production Per Capita of CFC-11 and CFC-12 Has Been Correlated With Gross Domestic Product (GDP) Per Capita in Developed Countries (1962 to 1980)



Production per capita of CFC-11 and CFC-12 for nonaerosol applications has been correlated with GDP per capita in the United States and other OECD countries.

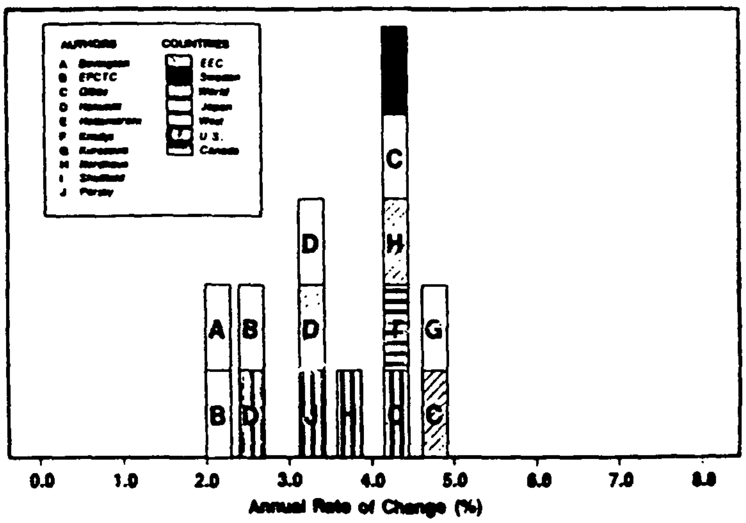
Source: CFC production, population, and GDP data obtained from: Gibbs, Michael J., (1986), Scenarios of CFC Use: 1985 to 2075, ICF Incorporated, prepared for the U.S. Environmental Protection Agency.

Concentrations Are Predicted to Rise

Market studies based on extensive economic analysis by several authors for a variety of geographic areas predict continued growth in these chemicals. Longer-term studies suggest growth rates of between 1-4% per year. Based on these analyses, from now until 2050, an average growth of 2.5% appears most likely.

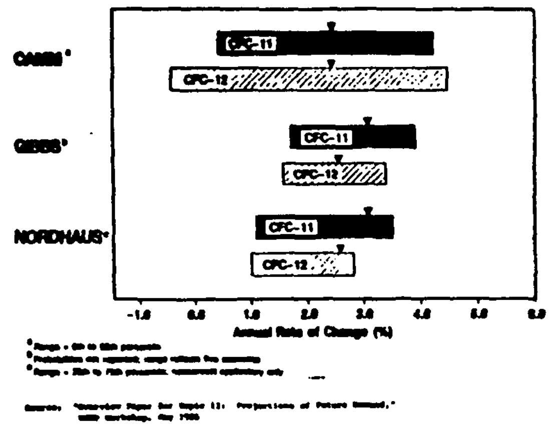
EXHIBIT 6

Short-Term Non-Aerosol Projections: CFC-11 and CFC-12 (1985-2000)



Source: "Overview Paper for Topic #2: Projections of Future Demand," UNEP Workshop, May 1986

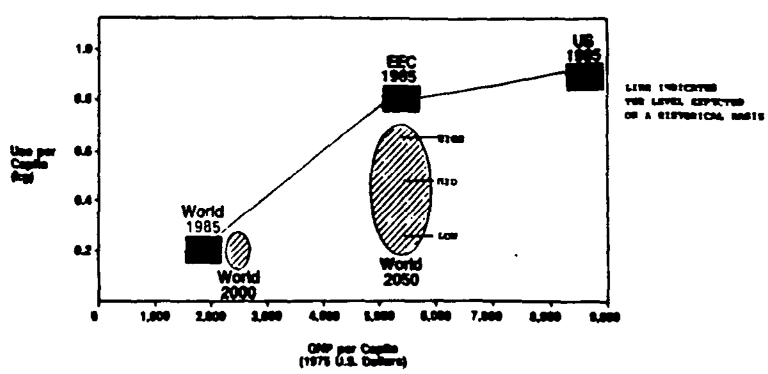
Long-Term Projections CFC-11 and CFC-12 -- World Production (2000-2050)



Based on these projections, the future growth of CFCs would be below historical levels. Exhibit 7 shows that world GNP per capita in 2050 is expected to roughly be equivalent to that of Europe today and slightly more than half that of the U.S. Despite the growth in world income, global CFC use would be considerably less than that of either the U.S. or Europe today. This analysis suggests that, in the absence of regulation, CFC use will continue to grow, but at reduced rates as technological change improves the efficiency of use or shifts consumers to alternatives.

EXHIBIT 7

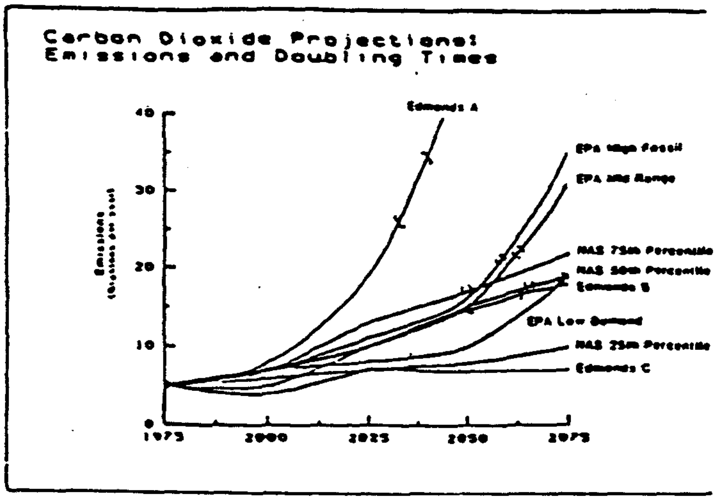
Current and Projected Future CFC-11 and CFC-12 Use Per Capita and GNP Per Capita



Projections of future trends in CO_2 are based on extensive energy modelling and analysis. Exhibit 8 shows a wide range of estimates based on varying assumptions about economic growth, non-fossil alternatives, energy conservation, etc. For the purposes of the central case, we have relied upon the 50th percentile case developed by Nordhaus (NAS 1983).

EXHIBIT 8

Projected Carbon Dioxide Emissions and Doubling Time of Concentrations



CO_2 emission projections are shown for EPA (Seidel and Keyes 1983); NAS (Nordhaus and Yohe 1983): and Edmonds (Edmonds et al., 1984). The brackets indicate the approximate time at which concentrations reach twice the pre-industrial level.

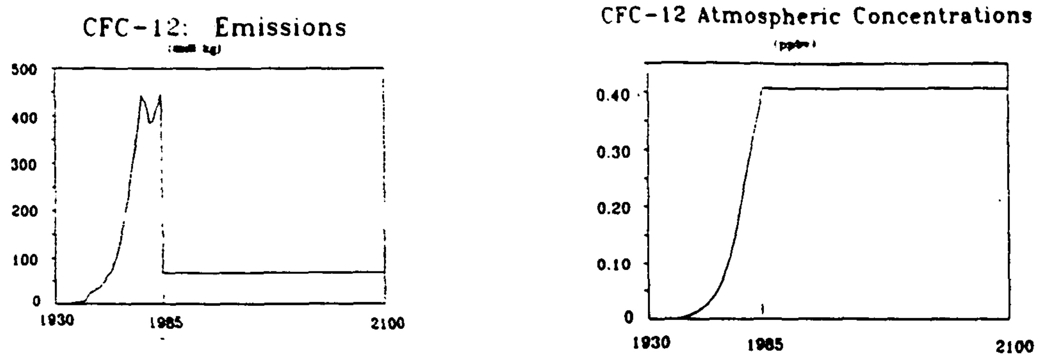
N_2O measurements and analysis of sources and sinks have been more limited. However, recent atmospheric measurements show a 0.25% annual increase. For the purposes of developing scenarios, this annual growth rate has been extended into the future.

Future trends in methane concentrations are difficult to determine. Scientific understanding of its sources and sinks is limited. However, its relatively short atmospheric lifetime (of about 10 years), suggests that changes in emissions over time could substantially influence atmospheric levels. In the absence of better information, we assume that recent increases of approximately 1.0% per year will continue in the future.

For evaluating risks, a critical relationship exists between emissions and atmospheric concentrations. CFC 11, 12, and 113 have atmospheric lifetimes of 75, 110, and 90 years respectively. This means that about 1/3 of current emissions will still be in the atmosphere for that length of time into the future. Since current emissions greatly exceed losses to the stratosphere, concentrations will rise even if emissions stop growing (Exhibit 9).

EXHIBIT 9

Relationship Between Emissions and Concentrations



A reduction of 85% in CFC-12 emissions (A) would be required to hold concentrations constant (B). Computed with simplified model of source and loss terms. See Appendix to Chapter 2.

ATMOSPHERIC RESPONSE

To explore the effects on ozone of changes in the atmosphere's chemical composition two approaches are utilized. First, measurements of recent changes in ozone levels and other atmospheric constituents can be compared to measured increases in CFCs and other trace gases. Second, models can be developed which attempt to replicate atmospheric processes affecting ozone levels. Moreover, the first approach can be used as an important source of information and validation of the second.

Ozone Monitoring

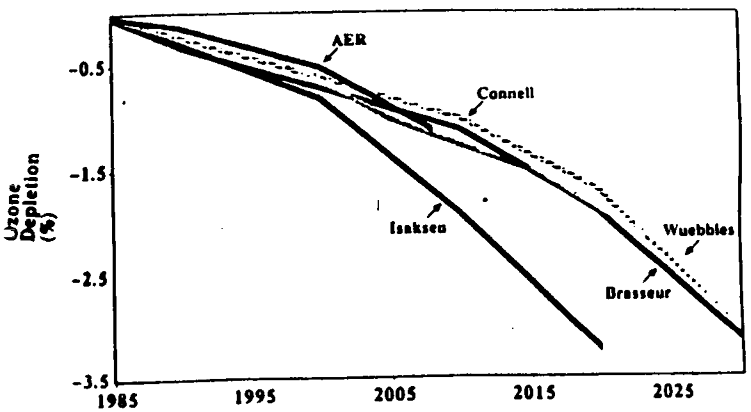
A range of monitoring using balloons and Umkehr readings show small, but significant, decreases of approximately 3 percent in the upper atmosphere at mid-latitudes and a 12 percent increase in ozone (from a smaller base) in the lower troposphere. Because of a lack of global distribution of ozone monitoring equipment, no acceptable method has yet been developed to aggregate stations to determine if net change has occurred on a global basis. Analysis using data for the period from 1970-80 suggests, however, that no significant net change in total column ozone has occurred.

Model Predictions

A relatively good consensus exists among models that treat the world as a single column of air (one-dimensional models), and among two-dimensional models (2-D) that consider seasonality and latitude. Of these model types, 2-D models project higher average depletion and show more depletion the further one moves from the equator (Exhibit 10).

EXHIBIT 10

Model Comparison for Coupled Scenario: 1-D and 2-D Model, Global Average



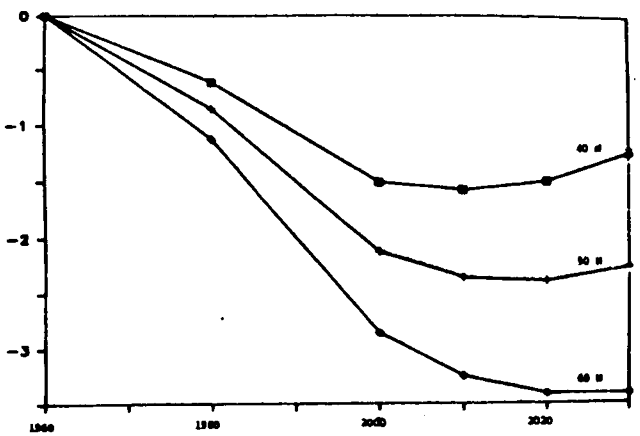
Global average change in total column ozone as calculated by several modeling groups for a common scenario of:

Compound	Growth Rate (% per year)
CFCs	3.0 (emissions)
CH4	1.0 (concentrations)
N2O	0.25 (concentrations)
CO2	~0.60 (concentrations)

Results shown for 2-D models of Isaksen and AER, 1-D models of Brasseur and Wuebbles, and Connell's parameterization of the LLNL 1-D model.

Source: Chemical Manufacturers Association, (1986); World Meterorological Organization, (1986); Connel, (1986); Brasseur and DeRudder, (1986); and Isaksen and Stordal, (1986).

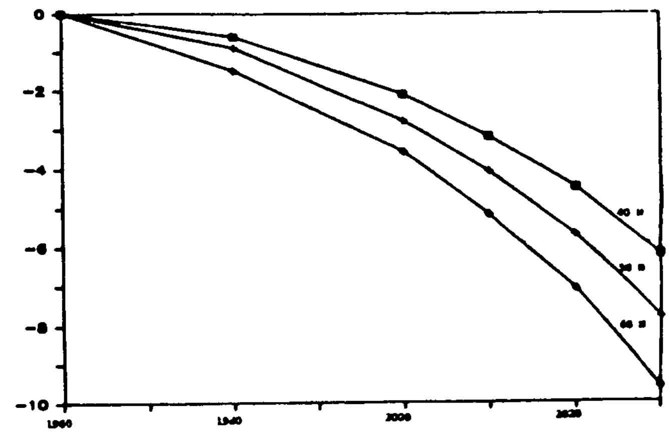
Two Dimensional Model: CFC Emissions Rolled Back to 1980 Levels



Results shown from constant CFC emissions at the 1980 level (approximately 10% less than current emissions for time dependent seasonally-averaged change in ozone for 1980 CFC emissions and coupled perturbations); CH4 concentrations at 1% per year, N2O concentrations at 0.25% per year, and CO2 concentrations at approximately 0.5% per year. Changes shown for 40°N, 50°N, and 60°N. Temperature feedback considered in model.

Source: Isaksen (personal communication).

Depletion by Latitude for 3% Growth CFCs



Results shown for time dependent seasonally-average changes in ozone for 3% growth per year in CFC emissions; 1% growth in CH4 concentrations; 0.25% growth in N2O concentrations, and approximately 0.5% growth in CO2 concentrations. Changes shown for 40°N, 50°N, and 60°N. Temperature feedback considered in model.

Source: Isaksen (personal communication).

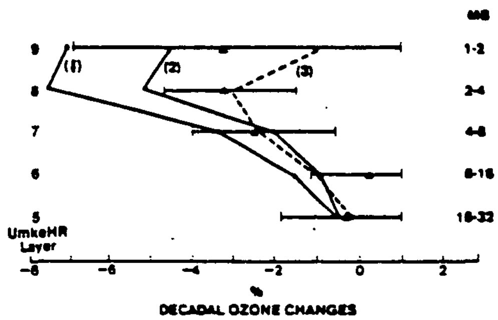
Testing Model Validity

As one test of their validity, model predictions can be compared against current atmospheric observations and historical changes. These comparisons show that current models do a relatively good job replicating most observations, but inconsistencies with some measurements of atmospheric constituents do occur. These inconsistencies reduce our confidence in the predictive capabilities of the current models.

Comparisons of models against upper stratospheric depletion estimates from the 1970 to 1980 timeframe show relative consistency (Exhibit 11).

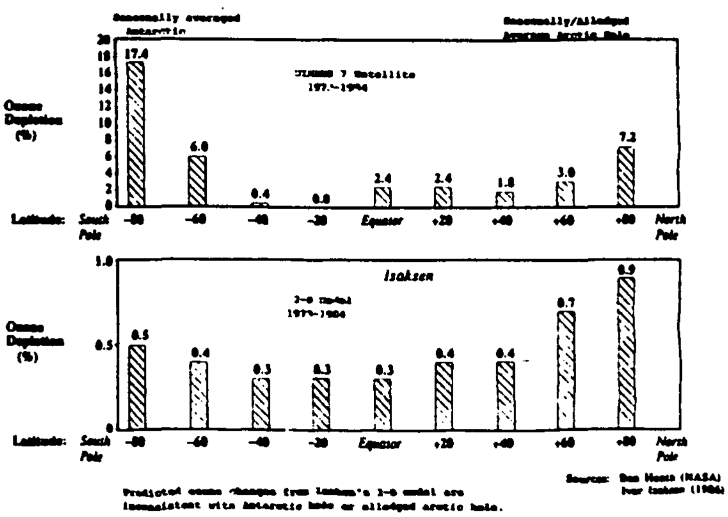
EXHIBIT 11

Calculated Ozone Depletion for 1970 to 1980 vs. Umkehr Measurements



In contrast, comparison of model results to the Antarctic ozone hole and to the alleged Arctic hole suggest that factors influencing this seasonal loss of ozone may not be incorporated in current models (Exhibit 12).

EXHIBIT 12



Until more information is available concerning the cause of the changes in Antarctica, revisions to these models would be unwarranted. Inadequate scientific evidence is available to determine whether the phenomenon is a precursor to future atmospheric behavior or merely an anomaly created by special geographical conditions unique to Antarctica.

Scientific analysis of the alleged "Arctic hole" has not proceeded far enough to draw any conclusions about whether it is real or temporary, or to determine its cause. Consequently, neither phenomenon provides a basis for revising model depletion estimates, although they clearly raise the possibility of missing chemistry (or aerosols, for example). Continued research and analysis could in the future necessitate a revision of risk estimates.

Uncertainties in Laboratory Inputs

The uncertainties about kinetic rates based on laboratory experiments were examined in several studies. This represents one possible area of uncertainties in current model configurations. These studies suggest that depletion is likely if CFCs grow, and that depletion significantly greater than predicted in the standard case is more likely than depletion significantly smaller.

Global Warming

Global warming is considered likely as a result of increases in these trace gases, including vertical reorganization of ozone in the stratosphere and increased water vapor. As a benchmark, the magnitude of warming has been estimated as $3^{\circ}C \pm 1.5^{\circ}C$ for doubled CO_2 or the radiative equivalent in other gases. The primary source of uncertainty is the feedback from clouds. The timing of this warming is considered uncertain because of delays currently estimated of 10-40 years due to oceanic heat absorption. Regional climatic change cannot yet be reliably predicted. Only gross characteristics are possible such as, increased warming the further one moves toward the poles, intensified hydrological cycles, and changes in the wetness or dryness of most of the world's regions. The global warming predicted for standard scenarios is shown in (Exhibit 13).

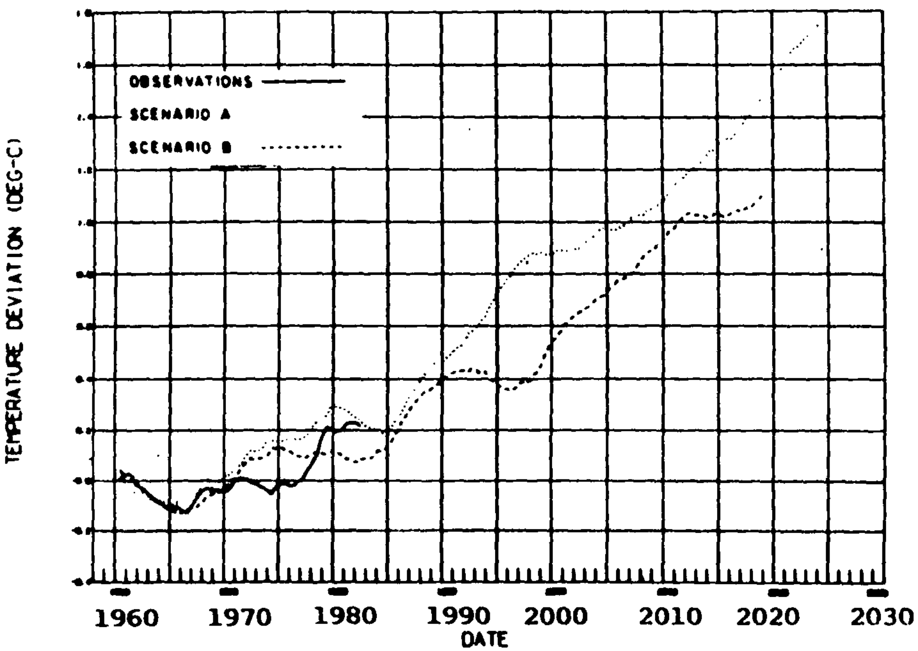
RISKS TO HUMAN HEALTH

Because UV-B varies by latitude under current conditions, a natural experiment exists with more UV-B radiation affecting those living closer to the equator than those located nearer the poles. Based on extensive laboratory studies and epidemiological analysis, basal and squamous skin cancer have been demonstrated to be related to UV-B radiation and can be expected to increase with ozone depletion (Exhibit 14). Death is fairly infrequent for these cancers -- about 1% of cases are fatal with the preponderance of deaths resulting from squamous cancers.

EXHIBIT 13

A 3-D Time Dependent Model Projection
Realized Temperature Increases

Results of Transient Analysis Using a General Circulation Model



A 1-D Time Dependent Model Projection
of Equilibrium Temperature

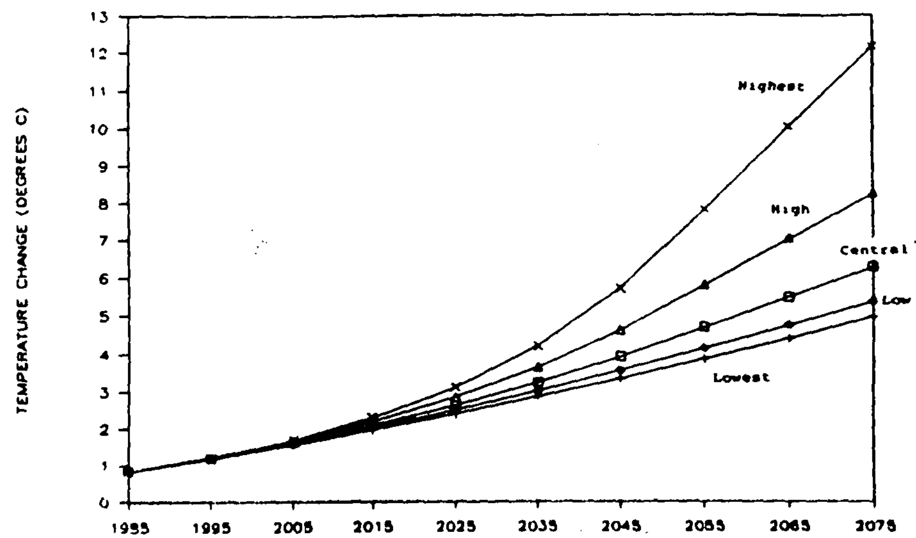


Exhibit 13

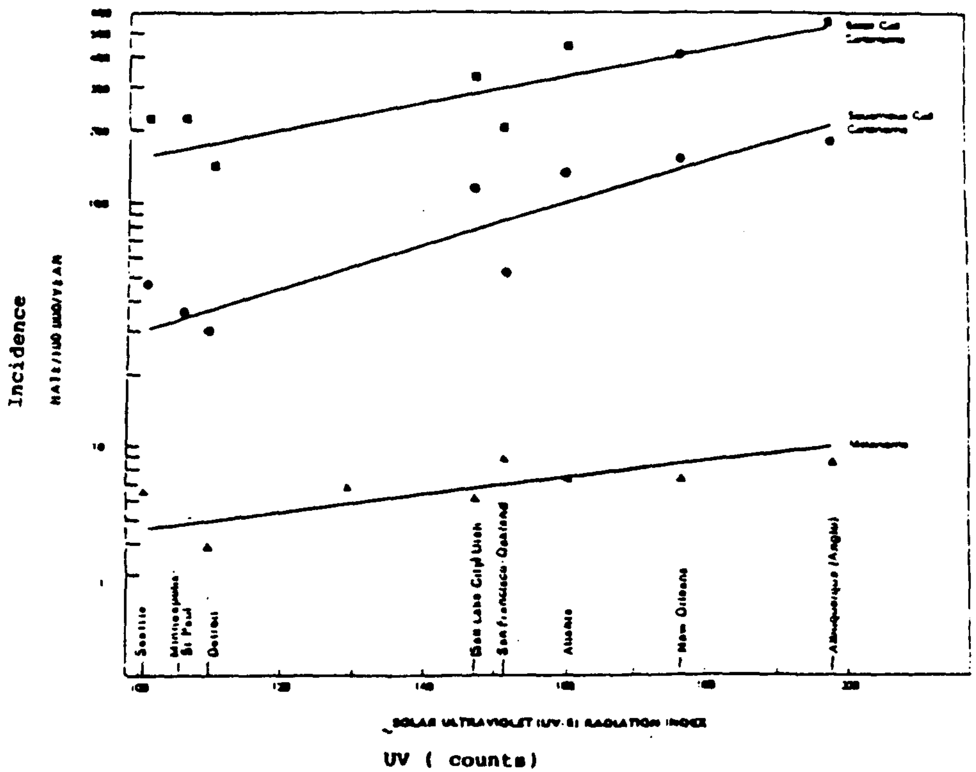
Only two time-dependent simulations have been conducted using a general circulation model. The results, shown above, indicate an increase in global average temperature of approximately 0.9°C by the year 2000 for Scenario A (which is a continuation of current rates of growth in trace gases). Scenario B (which reflects reduced rates of trace gas growth) indicates a warming of about 0.5°C by 2000. Scenario A achieves a radiative forcing equivalent to that of doubled CO2 about 40 years from now; Scenario B requires 75 years. Temperature equilibrium warming in this model is 9°C for doubled CO2.

* Computed assuming that the climate sensitivity to a doubling of carbon dioxide is 3°C. This assumption is in the middle of the NAS range of 1.5°C to 4.5°C (see Chapter 6). Note that the actual warming that may be realized will lag by several decades or more.

Source: Hansen 1985

EXHIBIT 14

Relationship Between UV and Skin Cancer Incidence



Project Percentage Change in Incidence of Basal and Squamous Cell Skin Cancers for a Ten Percent Depletion in Ozone for San Francisco Using DNA Action Spectrum

	Setlow DNA Low	Mid	High
Basal			
Male	21.15	30.41	40.45
Female	6.72	16.43	26.97
Squamous			
Male	33.95	51.87	72.19
Female	35.34	57.93	84.68

* According to annual UVB measurements at selected areas of the United States, with regression lines based on an exponential model.

Source: Scotto and Fraumeni (1982).

Melanoma is a more deadly form of skin cancer and there is greater uncertainty attached to its relationship to UV-B. While there is not proof that UV-B causes melanoma, overall the evidence supports a judgment that it is an important contributing factor (Exhibit 15).

EXHIBIT 15

Information That Has Been Interpreted As Supporting the Conclusion that Solar Radiation is One of Causes of Cutaneous Malignant Melanoma (CMM)

- Whites have higher CMM incidence and mortality rates than blacks.
- Light-skinned whites including those who are unable to tan or who tan poorly, get more CMM than darker-skinned whites.
- Sun exposure leading to sunburn apparently induces melanocytic nevi.
- Individuals who have more melanocytic nevi, develop more CMM; the greatest risk is associated with a particular type of nevus--the dysplastic nevus.
- Sunlight induces freckling, and freckling is an important risk factor.
- 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.
- Immigrants who move to sunnier climates have higher rates of CMM than populations in their country of origin and develop rates approaching those of the adopted country; this increase in risk is particularly accentuated in individuals arriving before the age of puberty (10-14 years).
- CMM risk is associated with childhood sunburn; this association may reflect an individual's pigmentary characteristics or may be related to nevus development.
- Most studies that have used latitude as a surrogate for sunlight or UVB exposure have found an increase in the incidence or mortality of CMM as one approaches the equator.
- Patients with xeroderma pigmentosum who cannot repair UVB-induced lesions in skin DNA have a 2000-fold increased risk of CMM by the age of 20.
- One form of CMM, Hutchinson's melanotic freckle melanoma, appears almost invariably on the chronically sun damaged skin of older people.

Information That Has Been Interpreted As Not Supporting the Conclusion that Solar Radiation is One of Causes of Cutaneous Melanoma

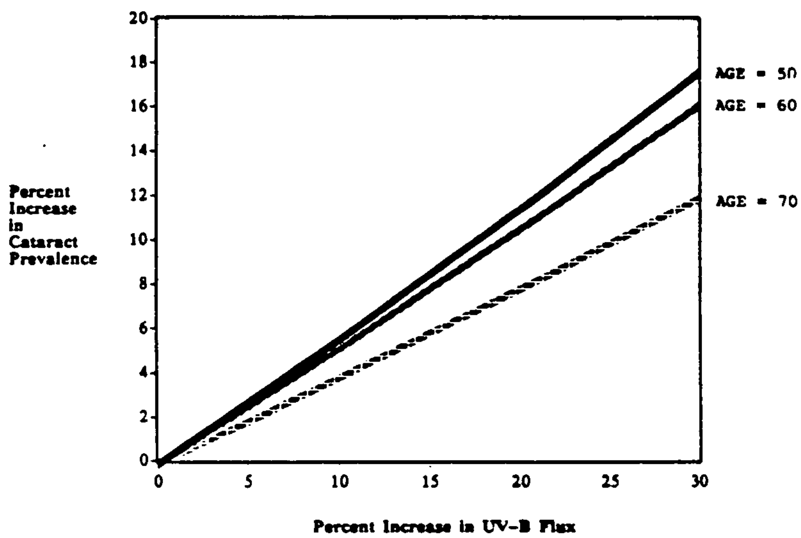
- Some ecologic epidemiology studies have failed to find a latitudinal gradient for CMM.
- Outdoor workers generally have lower incidence and mortality rates for CMM than indoor workers.
- Unlike basal cell and squamous cell carcinomas, most CMM occurs on sites that are not habitually exposed to sunlight.

Laboratory experiments and case studies demonstrate that UV-B can suppress the immune system in animals and humans. This response is thought to be a factor in the development of skin cancer. In addition, two infectious diseases, herpes and leishmaniasis, appear to be affected by UV-B, in part, due to suppression of the immune system. Other diseases have not been studied.

Although scientific understanding of the causes of cataracts is incomplete, UV-B exposure appears to be one contributing factor to their development. Epidemiological studies, animal studies, and biochemical analysis provide support for linking UV-B and cataracts, though other factors including exposure to UV-A also play a role (Exhibit 16).

EXHIBIT 16

Estimated Relationship Between Risk of Cataract and UV-B Flux



Although curable, cataracts in the U.S. still cause one-third of all blindness. In less developed countries, the health hazards are more severe.

RISKS TO TERRESTIAL CROPS AND AQUATIC ECOSYSTEMS

Because the current species of plants have evolved under existing radiation conditions, the question arises as to their ability to grow under elevated exposure to UV-B. Early studies tested tolerance to UV-B in greenhouses and showed substantial susceptibility for many cultivars. However, limited experiments under field conditions have demonstrated that to some extent a photorepair mechanism reduces damage.

Soybeans are the crop that has been tested most extensively. These field studies conducted for a period of over five years show that for a particular cultivar reductions in yield of up to 25 percent are possible for a 20 percent depletion of ozone.

Field experiments have also demonstrated that competitive balances between plants can be influenced by higher UV-B. The implications cannot be calculated, however, due to the lack of understanding about current ecosystem dynamics and the paucity of field experiments on the subject.

The use of selective breeding to choose genotypes insensitive to UV-B may be possible. However, because the genetic basis for resistance is not adequately understood, this mitigation approach remains uncertain.

Consequently, while evidence indicates that yield from some cultivars of crops may be reduced, the magnitude and dimensions are uncertain.

Based on laboratory experiments aquatic organisms appear to have low thresholds to UV-B exposure. Enhanced UV-B would probably alter the community composition of phytoplankton, which are at the bottom of the food chain and which must remain close to the waters surface to absorb sunlight. Larvae of commercially important aquatic organisms also appear subject to damage from enhanced UV-B. The great uncertainties, however, are the extent of exposure to enhanced UV-B in natural conditions in which water mixing and turbulence may play a role, and the life cycles of the organisms. Current information suggests a significant risk. For example, one study showed a 8% anchovy loss for a 9% depletion. But current knowledge is insufficient to determine the actual dimensions or magnitude of the risk.

RISKS TO POLYMERS

Ultraviolet-B radiation harms polymers, causing cracking, yellowing, and other effects that reduce their useful life. Stabilizers can be added, at a cost, to reduce damage, although in some cases they may also reduce product viability. Increases in humidity and temperature could exacaberate harm to polymers.

Due to a lack of experimental data, uncertainty exists about the effects of UV-B and ozone depletion on polymers, requiring approximate estimation methods to be used.

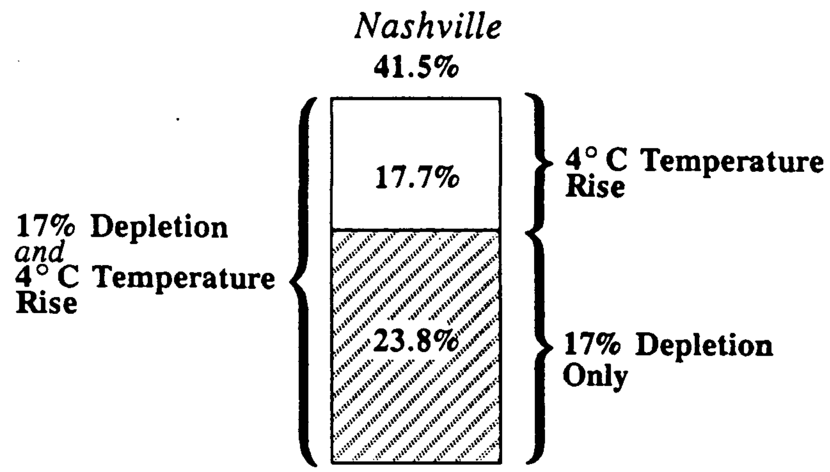
Only one polymer has been analyzed in detail -- polyvinylchloride (PVC). Based on a single study, 26% ozone depletion by 2075 would cause a cumulative economic damage of 4.7 billion dollars (undiscounted) in the U.S.

RISKS TO TROPOSPHERIC AIR POLLUTION

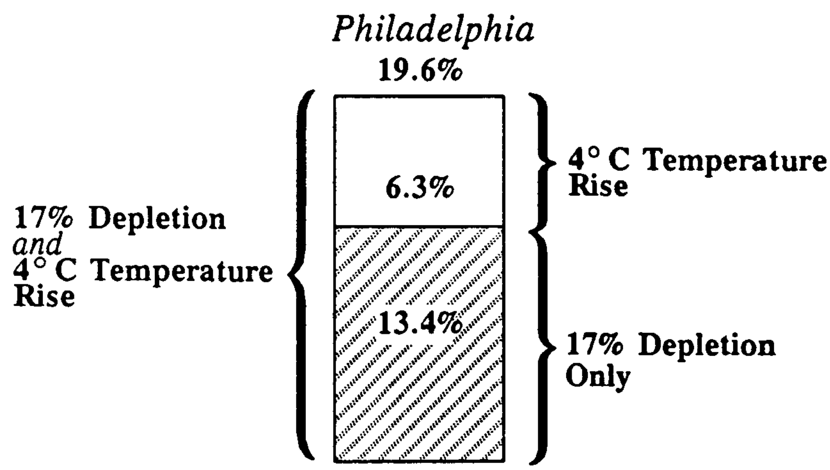
One study recently analyzed the effects of increased UV-B on the formation of ground-based oxidants (i.e., smog). It showed that in three cities increases in UV-B could increase ground-based ozone (regulated by EPA at 0.12 ppm), with global warming excaberating the situation (Exhibit 17). Ground-based ozone would also form earlier on the day, exposing larger numbers of people to peak values.

EXHIBIT 17

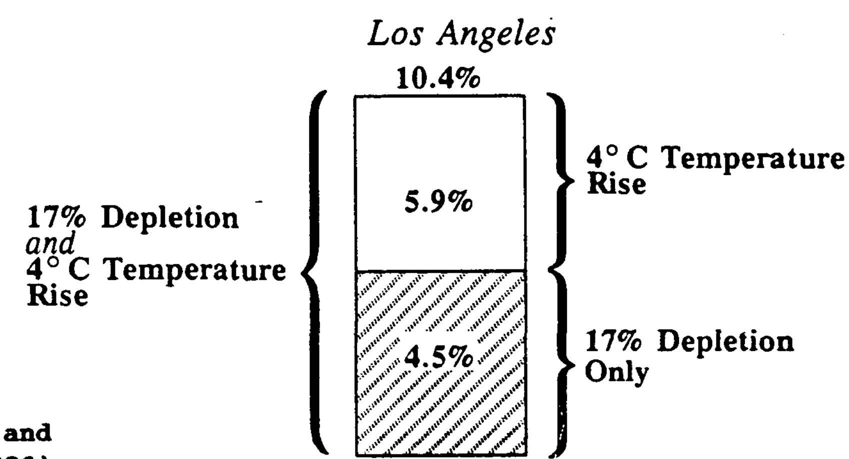
Global Warming Would Exacerbate Effects of Depletion on Ground-Based Ozone



Increase in Ground-Based Ozone



Increase in Ground-Based Ozone



Source: Whitten and Gery (1986)

Increase in Ground-Based Ozone

In addition, a preliminary study indicates a strong relationship between UV-B and hydrogen peroxide, an oxidant and acid rain precursor. In Los Angeles the effect of 33% depletion was to double hydrogen peroxide; in Philadelphia it would increase by a factor of 16. These findings need to be verified in chamber tests.

RISKS FROM CLIMATE CHANGE

CFCs and stratospheric modification may contribute as much as 40-50% of total predicted global warming in high trace gas growth cases and 20-30% in the central case. Estimates of the effects of climate change are in early stages of research.

Potential Increases and Effects of Sea Level

Different studies have analyzed the potential contributions to sea level rise from different sources. Several have made estimates of thermal expansion due to global warming. One study has also estimated alpine mountain runoff and its contribution to sea level rise, while others have looked at the potential contribution from deglaciation. The estimates are quite consistent (Exhibit 18).

EXHIBIT 18

Estimates of Future Sea Level Rise (centimeters)

Year 2100 by Cause (Year 2085 for Revelle 1983):

	Thermal Expansion	Alpine Glaciers	Greenland	Antarctica	Total
Revelle (1983)	30	12	12	2	70
Hoffman et al. (1983)	28-115	b/	b/	b/	56-345
Meier et al. (1985) c/	-	10-30	10-30	-10-+100	50-200
Thomas (1985)	-	-	-	0-200	-
Hoffman et al. (1986)	28-83	12-37	6-27	12-220	57-368

a/ Revelle attributes 16 cm to other factors.

b/ Hoffman et al. (1983) assumed that the glacial contribution would be one to two times the contribution of thermal expansion.

c/ NAS (1985) estimate includes extrapolation of thermal expansion from Revelle (1983).

Sources: Hoffman et al. (1986); Meier et al. (1985); Hoffman et al. (1983): Revelle (1983); Thomas (1985).

Sea level rise can be expected to innundate marshes, erode coastal areas, increase flooding, and cause saltwater intrusion (Exhibit 19).

One study estimated that a 100 to 200 cm sea level rise would eliminate 50 to 80% of coastal wetlands depending, in part, on whether new wetlands are allowed to form or whether developed areas are protected. Several case studies have demonstrated that specific recreational beaches would disappear, unless periodic beach and island nourishment with sand occurred. Case studies of Galveston and Charleston indicate that significant economic damage would occur, particularly from flooding. These studies also show that anticipatory planning can significantly reduce damages.

Other studies suggest river deltas are particularly at risk from sea level rise. Much of the Mississippi delta is already expected to disappear over time due to subsidence; sea level rise would accelerate this problem. In Bangladesh and Egypt, one study estimated that subsidence and global sea level rise could cause displacement of 16-21 percent of Egypt's population and 9-21 percent of the population of Bangladesh.

Possible Effects on Forests

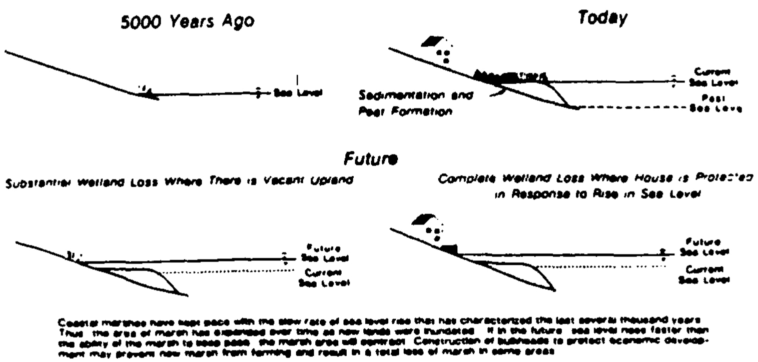
Climate models predict that a global warming of approximately 1.5°C to 4.5°C will be induced by a doubling of atmospheric CO2 or equivalent radiative increases from other trace gases. This CO2 doubling or its equivalent is likely to take place during the next 50 to 100 years. The period 18,000 to 0 years B.P. is one possible 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, though historically this occurred over a much longer time period.

The paleovegetational record shows that climatic change as large as that expected to occur in response to a CO2-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 Florida along with oak and hickory.

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 CO2 environment. Plant taxa will respond individually rather than as whole communities to regional changes in climate variables. At this time 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.

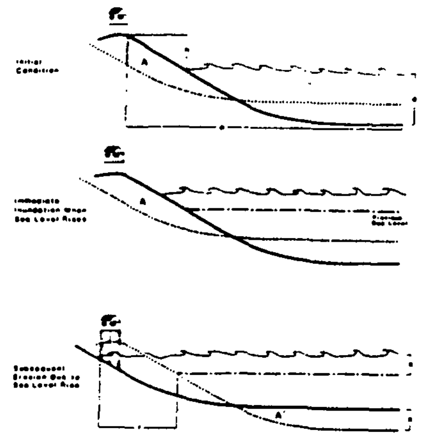
EXHIBIT 19

Evolution of March as Sea Level Rises



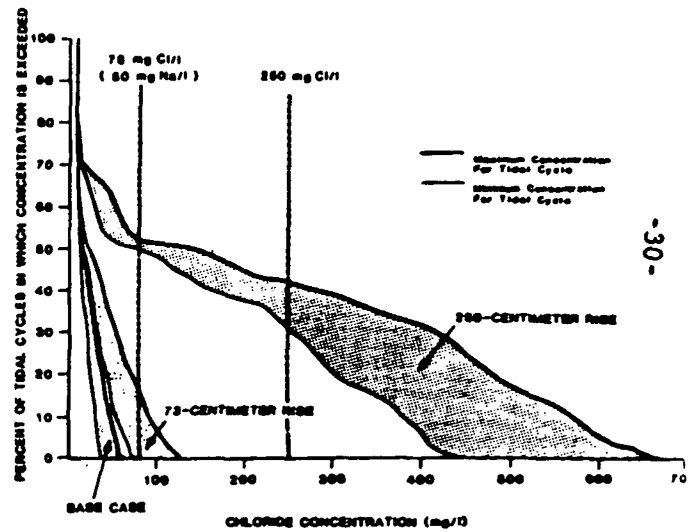
Coastal marshes have kept pace with the slow rate of sea level rise that has characterized the last several thousand years. Thus, the area of marsh has expanded over time as new lands were inundated. If in the future, sea level rises faster than the ability of the marsh to keep pace, the marsh area will contract. Construction of bulkheads to protect economic development may prevent new marsh from forming and result in a total loss of marsh in some areas

Erosion; The Bruun Rule



A rise in sea level of S causes immediate inundation. However it would eventually require the offshore bottom to rise by S. The necessary S and A' would be supplied from the upper part of the beach A. Total shoreline retreat r is equal to S * p/(h+d)

Saltwater Intrusion



Percent of tidal cycles in which specified concentration is exceeded at Torresdale during a recurrence of the 1960's drought for three sea level scenarios. The 250 mg Cl/l level is the EPA drinking water standard for chloride The 50 mg/l Na level is the New Jersey sodium standard

Source: Hill et al 1981

* * * DRAFT FINAL * * *

Possible Effects on Crops

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% 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.

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.

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 the likelihood of a five consecutive daily maximum temperature event of at least 35°C (95°F) by about a factor of three for a city like Des Moines. In regions where crops are grown close to their maximum tolerance limits, changes in extreme temperature events may have significant harmful effects on crop growth and yield.

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.

Higher ambient CO2 levels may enhance plant growth, decrease water use, and thereby increase crop yield and alter competitive balances in ecosystems. These factors must be evaluated in conjunction with changes in climate regimes. Large uncertainties exist because few long-term and multiple stress studies have been completed.

Possible Effects on Water Resources

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.

The inextricable linkages between the water cycle and climate ensure that future climate change will significantly alter hydrological processes throughout the world. All natural hydrological processes -- precipitation, infiltration, storage and movement of soil moisture, surface and subsurface runoff, recharge of groundwater, and evapotranspiration -- will be affected be affected if climate changes. Until models of regional climate change are improved, it will be difficult to obtain an understanding of the risks associated with gloal warming.

Possible Effects on Human Health

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

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% of that total.

Hot weather extremes appear to have a more substantial impact on mortality than cold wave episodes. Most research indicates that mortality during extreme heat events varies with age, sex, and race. Acclimatization may moderate the impact of successive heat waves over the short-term.

Threshold temperatures for cities have been determined which represent maximum and minimum temperatures associated with increases in total mortality. These threshold temperatures vary regionally, i.e., the threshold temperature for winter mortality in mild southern cities such as Atlanta is 0°C and for more northerly cities such as Philadelphia, the threshold temperature is -5°C. Humidity and precipitation also have an important impact on mortality, since it contributes to the body's ability to cool itself by evaporation of perspiration.

If future global warming induced by increased concentrations of trace gases does occur, it has the potential to significantly affect human mortality. 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 is 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.

AN INTEGRATED ANALYSIS OF RISKS OF STRATOSPHERIC MODIFICATION

In order to assess risks from stratospheric modification in the absence of any future regulatory action, the various assumptions (e.g., trace gas growth, atmospheric response, incidence of skin cancer, etc.) have to be linked in an integrated modelling framework. Since significant uncertainty exists about each component, a central case was estimated along with alternative assumptions.[1]

---

[1] The central case estimates reflect the most likely values of key assumptions and inputs used to model risks:

- Annual production of CFC 11 and 12 grow at an annual average rate of 2.5 percent from 1985 to 2050, and remains constant following 2050; growth rates for other chlorine and bromine substances as described in Chapter 3. The compounds analyzed include: CFC-11, CFC-12, CFC-22, CFC-113, methyl chloroform, carbon tetrachloride, Halon-1211, and Halon-1301. Emissions estimates reflect the storage of some substances in their end-use products for many years.

- Consensus estimates of the annual rates of increases in atmospheric concentrations of other trace gases are used: carbon dioxide (CO2) at 0.6 percent; methane (CH4) at 1.0 percent; and nitrous oxide (N2O) at 0.25 percent. Trace gas assumptions are discussed in Chapter 4.

- A parameterized relationship between emissions of ozone modifiers, trace gas concentrations and global ozone depletion is used. This equation reflects the results of a one-dimensional model of the atmosphere using the most recent estimates of reaction rates. The parameterized atmospheric model (described in Chapter 17) was derived from the LLNL Model developed by Wuebbles (reported in Chapter 5).

- The latitudinal distribution of ozone depletion is evaluated using the results of a time-dependent two-dimensional model of the atmosphere. The latitudinal analysis of ozone depletion is presented in Chapter 17.

- The relationship between changes in ozone abundance and changes in UV flux reaching the earth's surface is based on estimates of a radiation model of the atmosphere. The estimates of UV flux are described in Chapter 17.

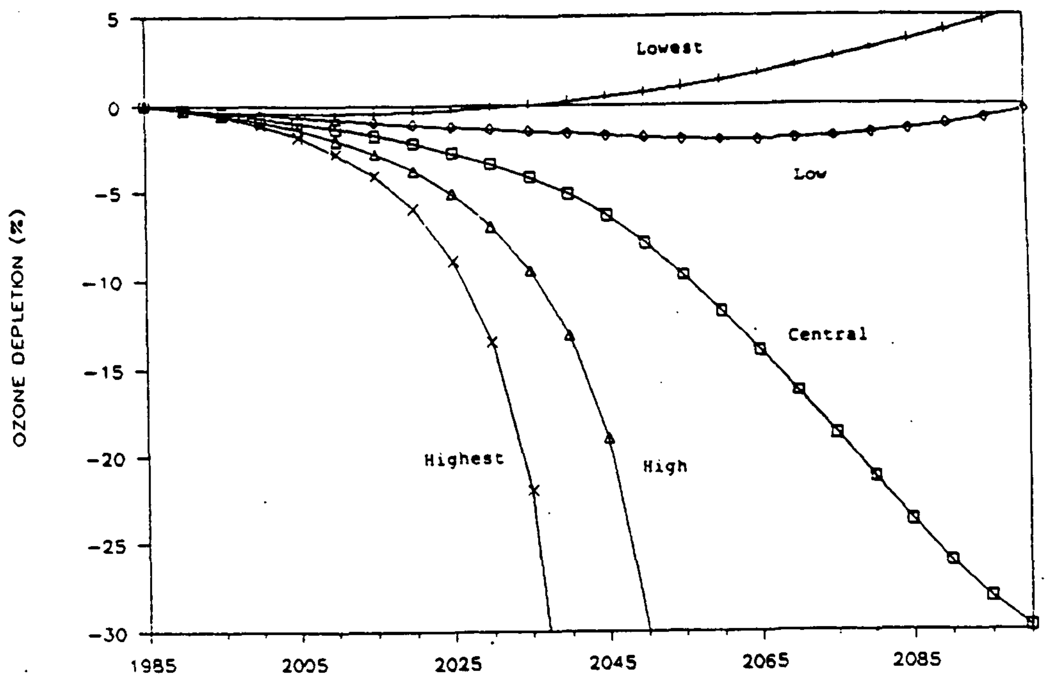
- The risks to human health due to increases in UV are evaluated using middle estimates of dose-response coefficients developed in epidemiologic analyses in the U.S. The quantifiable risks to human health are described in Chapters 7, 8, and 10.

- The middle estimate by the National Academy of Sciences (NAS) for the sensitivity of the global climate to greenhouse gas forcings is used -- 3.0°C equilibrium warming for a doubling of the concentration of CO2. The National Academy of Sciences estimates are presented in Chapter 6. Recent analyses of climate sensitivity indicate that a 4°C sensitivity may be a preferred central case assumption (Manabe and Wetherald 1986; Washington and Meehl 1984; Hansen et al. 1984).

Exhibit 20 shows predicted depletion for a range of cases with varying assumptions about trace gas growth.

EXHIBIT 20

Global Average Ozone Depletion: Emission Scenarios (LLNL 1-D Model Results)



Key Assumptions:

<u>Common to Each Scenario</u>

- CH_4 concentrations: 1% per year
- CO_2 concentrations: 0.6% per year
- N_2O concentrations: 0.25% per year

<u>Varying in Each Scenario</u>

Annual Growth in CFC-11 and CFC-12 production (%/year)

Lowest	0.0
Low	1.2
Central	2.5
High	3.8
Highest	5.0

Other CFCs, and chlorinated and brominated compounds also growing.

Exhibit 21 shows predicted health effects in the U.S for the central case assumptions.

EXHIBIT 21

Human Health Effects: Central Case (Additional Cumulative Cases and Deaths by Population Cohort)

HEALTH EFFECT	POPULATION ALIVE TODAY[a]	NUMBERS BORN 1985-2029[b]	NUMBERS BORN 2030-2074[c]
Non-Melanoma Skin Tumors			
Additional Basal Cases	630,600	5,012,900	17,630,500
Additional Squmaous Cases	386,900	3,185,800	12,122,400
Additional Deaths	16,500	135,000	509,300
Melanoma Skin Tumors			
Additional Cases	12,300	109,800	430,500
Additional Deaths	3,900	32,200	115,100
Senile Cataract			
Additional Cases	593,600	3,463,400	8,295,800

[a] Analysis period for health effects: 1985-2074.

[b] Analysis period for health effects: 1985-2118.

[c] Analysis period for health effects: 2030-2164.

Exhibit 22 presents limited evidence from case studies for other key effects based on the central case assumptions.

Sensitivity to Assumptions About Greenhouse Gases that Counter Depletion

The above case assumes unconstrained greenhouse gas growth. Exhibit 23 examines an alternative set of assumptions which consider the possibility that future actions might be taken by governments to limit climate change.

EXHIBIT 22

Materials, Climate and Other Effects: Central Case

TYPE OF EFFECT	EFFECT	UNITS
Effects Estimated Quantitatively for the U.S.		
Materials Damage a/	550	Present Value (millions of 1985 dollars)
Rise in Equilibrium Temperature by 2075 b/	6.2	Degrees Centigrade
Sea Level Rise by 2075	101	Centimeters
Effects Based on Case Studies and Research in Early Stages		
Cost of Sea Level Rise in Charleston and Galveston c/	1,145-2,807	Present Value (millions of 1985 dollars)
Reduction in Soybean Seed Yield d/	14.3	Percent in Year 2075
Increase in Ground-Based Ozone e/	5.1-27.2	Percent in Year 2075
Loss of Northern Anchovy Population f/	3.8-19.8	Percent in Year 2075

a/ Discounted over 1985-2075 using a real discount rate of 3 percent.

b/ Estimated using an assumed climate sensitivity of 3°C (middle NAS estimate). Recent analysis indicates that 4°C may be a preferred central case assumption. Using a 4°C sensitivity, the estimated equilibrium warming in 2075 is about 8.4°C.

c/ Lowest estimate with anticipation of sea level rise; highest estimate without anticipation.

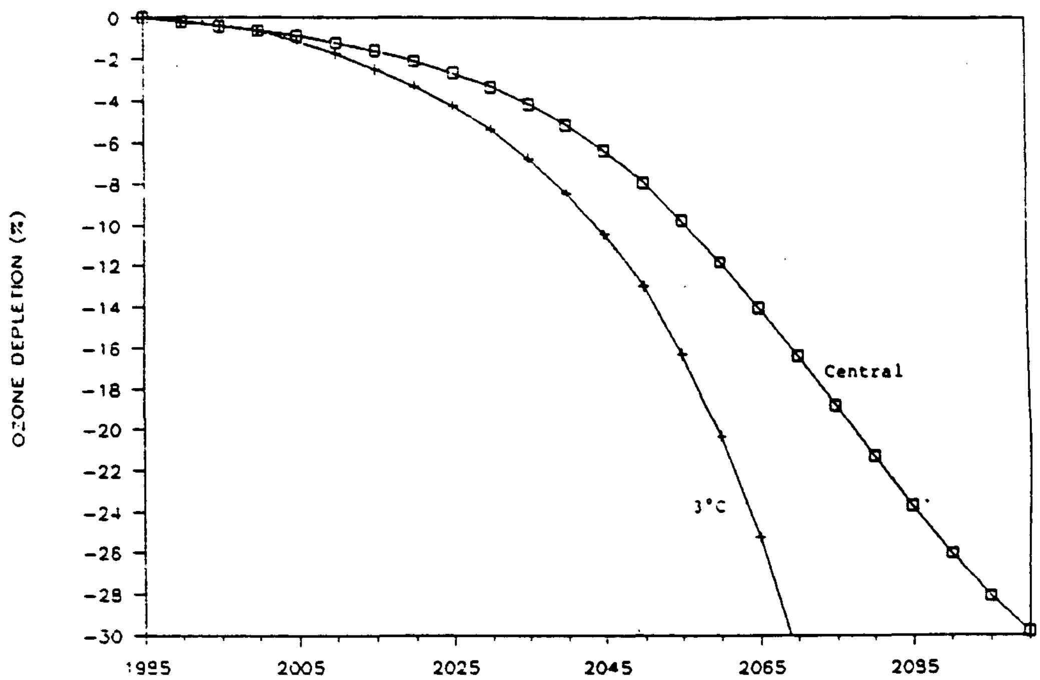
d/ Essex cultivar only in years of average current climate.

e/ Lowest estimate is for Los Angeles, California; highest estimate is for Nashville, Tennessee.

f/ Lowest estimate assumes 15-meter vertical mixing of the top ocean layer; highest estimate assumes 10-meter vertical mixing.

EXHIBIT 23

Global Average Ozone Depletion: Scenario of Limits to Future Global Warming



It shows the effects of ozone depletion if steps were taken to limit growth as trace gas emissions to the level of greenhouse warming of 3°C. By limiting the buffering of ozone depletion by the growth in these greenhouse gases, the negative effects of CFCs and halons on ozone in the stratosphere is increased.

Exhibits 24 and 25 show the effects on health effects and other factors for the same assumptions of limited greenhouse gas growth.

Comparison of One-Dimensional Model to a Two-Dimensional Model

The estimates given above are derived from the one-dimensional model used throughout this review. Comparison of these global ozone depletion estimates to those from a two-dimensional model, indicate that it produces levels of ozone depletion slightly less than half of those by a two-dimensional model (Exhibit 26).

EXHIBIT 24

Cumulative Health Effects for People in U.S. Alive Today and Born in Next 88 Years With Greenhouse Gases Limited

HEALTH EFFECT	LIMITS TO FUTURE GLOBAL WARMING 3°C ± 1.5°C *	Central Case (no limit)
Non-Melanoma Skin Tumors		
Additional Basal Cases	50,984,500	23,274,000
Additional Squamous Cases	41,814,400	15,695,100
Additional Deaths	1,726,000	660,800
Melanoma Skin Tumors		
Additional Cases	1,137,600	552,600
Additional Deaths	308,500	151,200
Senile Cataract		
Additional Cases	22,817,600	12,352,800

* Uncertain of ±1.5°C due to uncertainty about true sensitivity of earth to radiative forcing (e.g., same greenhouse gas increase).

EXHIBIT 25

Materials, Climate, and Other Effects: Scenarios of Limits to Future Global Warming
(Figures in Parentheses are Percentage Changes from Central Case)

TYPE OF EFFECT	LIMITS TO FUTURE GLOBAL WARMING 3 C	Central Case (no limit)	UNITS
Effects Estimated Quantitativety for the U.S.			
Materials Damage a/	726	550	Present Value (millions of 1985 dollars)
Rise in Equilibrium Temperature by 2075	3.0 (-52)	6.2	Degrees Centigrade
Sea Level Rise by 2075	76 (-25)	101	Centimeters
Effects Based on Case Studies and Research in Early Stages			
Cost of Sea Level Rise in Charleston and Galveston b/	967-2328	1145-2807	Present Value (millions of 1985 dollars)
Reduction in Soybean Seed Yield c/	>19.0	14.3	Percent in Year 2075
Increase in Ground-Based Ozone d/	>9.4->50.0	5.1-27.2	Percent in Year 2075
Loss of Northern Anchovy Population e/	>11.0->25.0	3.8-19.8	Percent in Year 2075

a/ Discounted over 1985-2075 using a real discount rate of 3 percent.

b/ Lowest estimate with anticipation of sea level rise; highest estimate without anticipation.

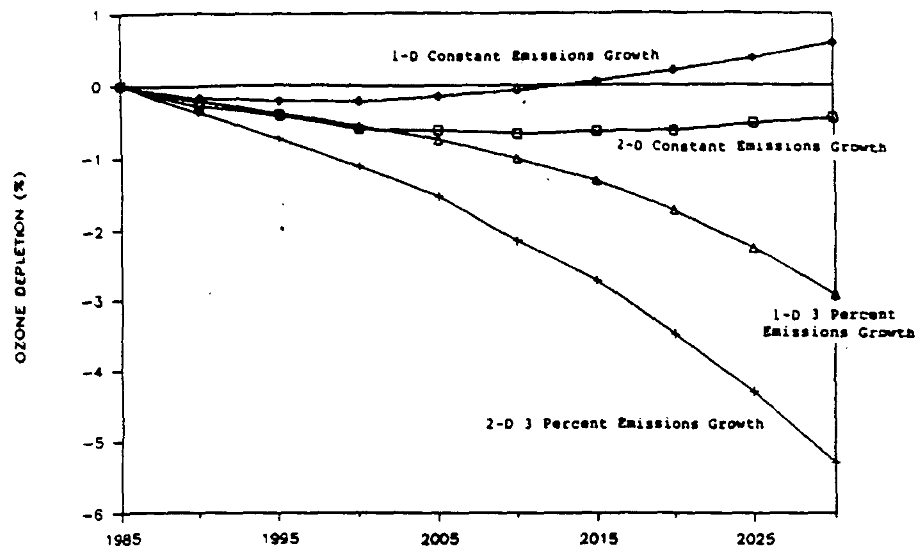
c/ Essex cultivar only in normal years.

d/ Lowest estimate is for Los Angeles, California; highest estimate is for Nashville, Tennessee.

e/ Lowest estimate 15-meter vertical mixing of the top ocean layer; highest estimate 10-meter vertical mixing.

EXHIBIT 26

Global Average Ozone Depletion: Comparison to Results with a 2-Dimensional Atmospheric Model



Sensitivity to Rate of CFC Growth

As shown in Exhibit 20, the amount of ozone depletion is sensitive to the assumption about future growth of CFCs and other trace gases (Exhibit 23). Assuming that other gases continue to increase, Exhibit 27 shows the impact on human health for different CFC growth scenarios.

Uncertainty About Health Dose-Repose Relationships

Uncertainty exists about the appropriate dose-response relationship for each of the human health effects. Exhibit 28 shows an analysis of the statistical uncertainty for each of thes areas.

OVERALL ASSESSMENT OF UNCERTAINTY

The largest quantitative uncertainties involve assumptions concerning future emissions of CFCs; future greenhouse gas growth; the use of 2-D models for predicting depletion, and uncertainties about dose-response parameters. Qualitatively the uncertainties for effects include implications of increased immune suppression; dose-response relationships for aquatics, crops, terrestial ecosystems; and a vary of climate impacts. With respect to modeling the atmospheric consequences of trace gas growth, there exists the possibility that some overlooked or missing factor or oversimplified process has lead to under- or over-predictions of changes in ozone.

EXHIBIT 27

Human Health Effects: Emissions Scenarios
Additional Cumulative Cases and Deaths Over Lifetimes of People Alive Today
(Figures in Parentheses are Percent Changes from Central Case)

HEALTH EFFECT	EMISSIONS SCENARIOS			EXTREME CASES	
	Low	Central	High	Lowest	Highest
Non-Melanoma Skin Tumors					
Additional Basal Cases	1,599,500	23,274,000	83,755,700	-1,616,100	135,317,800
Additional Squamous Cases	823,400	15,695,100	71,808,100	-856,600	117,809,800
Additional Deaths	35,700	660,800	2,952,400	-36,700	4,837,400
Melanoma Skin Tumors					
Additional Cases	47,300	552,600	1,897,400	-40,500	3,079,500
Additional Deaths	12,100	151,200	502,800	-11,200	809,700
Senile Cataract					
Additional Cases	885,000	12,352,800	34,226,900	-1,112,100	53,429,800

EXHIBIT 28

Human Health Effects: Sensitivity to Dose-Response Relationship Additional Cumulative Cases and Deaths Over Lifetimes of People in U.S. Alive Today and Born in Next 88 Years

HEALTH EFFECT	SENSITIVITY OF EFFECT TO UV DOSE Low	 Central	 High
Non-Melanoma Skin Tumors			
Additional Basal Cases	14,046,400	23,274,000	34,130,500
Additional Squamous Cases	9,242,000	15,695,100	24,385,300
Additional Deaths	109,200	660,800	10,203,000
Melanoma Skin Tumors			
Additional Cases	384,300	552,600	732,100
Additional Deaths	134,300	151,200	168,500
Senile Cataract			
Additional Cases	6,600,200	12,352,800	17,038,300

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

Dear Collegue:

Enclosed is a copy of the draft document you requested entitled, An Assessment of the Risks of Stratospheric Modification prepared by the Strategic Studies Staff of the U.S. EPA. This document was submitted to the Science Advisory Board on October 23,1986. On November 24 and 25 the Science Advisory Board, chaired by Dr. Margaret Kripke will meet to review the document.

The review process of this document follows the traditional procedure used by the Science Advisory Board. This includes:

- Public notice of the Subcommittee's November 24-25 meeting in the Federal Register (in order to conform to the legal requirements of the Federal Advisory Committee Act).

- Opportunity for succinct technical presentations to the Subcommittee by interested members of the public (the total amount of time allotted for such comments will not exceed one hour)

- A copy of the risk assessment document and comments received will be available for review at the Public Information Reference Unit, (202) 382-5926, EPA Headquarters Library, 401 M St, SW Washington, DC between the hours of 8:00 am and 4:30pm. The public docket number is A-86-18.

- When the SAB Subcommittee meets in November, there will be an exchange of scientific views between the Committee and the EPA staff. This informal exchange of views will cover any questions concerning the validity of the scientific assumptions, as well as the methodologies and conclusions of the assessment document. The Subcommittee will then develop a consensus position paper and a final report will be prepared. Following the finalization of the text, the report will be sent to the Science Advisory Board Executive Committee and then directly to the EPA Administrator. EPA will then have time to respond to the Subcommittee's report.

Written comments should be addressed to John S. Hoffman, at PM 220, U.S. EPA, 401 M St,SW , Washington, DC 20460. Comments are due to the SAB by November 14. The public comment period will be open until December 10.

GLOBAL MODELING OF THE ULTRAVIOLET SOLAR FLUX INCIDENT ON THE BIOSPHERE

George N. Serafino

Applied Research Corporation

8201 Corporate Drive

Landover, Maryland 20785

and

John E. Frederick

Department of the Geophysical Sciences

The University of Chicago

5734 South Ellis Avenue

Chicago, Illinois 60637

Abstract

This report summarizes an algorithm designed to estimate the ultraviolet solar flux that reaches the Earth's surface at any location on the globe and time of year. Inputs consist of global ozone abundances, terrain height, the distribution of cloudcover, and the albedos of clouds and the underlying surface. Intended users of the algorithm include atmospheric scientists, the photobiology community, and environmental policymakers.

I. Introduction

The interaction of solar radiation with the Earth and its atmosphere is closely coupled to the planet's ability to support life. Ultraviolet solar radiation likely initiated the chemical processes which led to formation of the first organic molecules on the primitive Earth (eg. Ponnamperuma, 1981), while the development of a substantial ozone layer created a surface environment where complex self-replicating molecules could evolve. The decreases shown by both the absorption cross section of ozone and the DNA action spectrum at wavelengths between 280 and 320 nm provide persuasive evidence of the coupling that has existed between the geophysical and biological realms which ultimately provided for the evolution of higher life forms.

Issues of more immediate practical concern center on the observation that the incidence of various skin cancers shows latitudinal variations. This appears related to the biologically active ultraviolet flux reaching the surface of the Earth. While this fact alone is of great significance, couplings of a more subtle nature apparently exist between the radiation environment and biological systems. A prime example is the work by DeFabo and Noonan (1983) which indicates a link between ultraviolet radiation dosage and suppression of the immune system in laboratory mice. Photobiologists have adopted the term UV-A to refer to radiation over the wavelength range 320-400 nm, while UV-B denotes the region 280-320 nm. Absorption by ozone and atmospheric scattering reduce the solar UV-B flux at the surface of the Earth to a small fraction of what would otherwise exist. The UV-A, being outside the range of strong absorption by ozone, experiences much less attenuation.

This report describes the conceptual formulation of an algorithm designed to predict the UV-B and UV-A radiation fluxes as functions of wavelength at any point on the Earth for any time of year. Papers which summarize the mathematical methods used in the code already exist in the published literature. We make reference to these rather than presenting details here. The algorithm utilizes global scale ozone measurements obtained by the Solar Backscattered Ultraviolet (SBUV) Spectral Radiometer carried on the Nimbus 7 satellite. We combine this data set with additional information on cloudcover and cloud transmission obtained from independent sources. While the development of the algorithm is an exercise in radiative transfer and atmospheric science, we intend the final product to be a tool for use by the photobiology community and environmental policymakers.

II. The Radiative Transfer Formulation

We divide the atmosphere into two parts, (1) the clear atmosphere above any cloudtops and (2) the cloud layer, the atmosphere beneath the cloud (the "sub-cloud layer"), and the ground. In the absence of clouds only case 1 is required. When clouds are present we merge a model of this portion of the atmosphere onto the base of the clear sky calculation. We assume that the lower boundary of the clear atmosphere, being cloudtops or ground, is a Lambertian surface of known albedo. A radiative transfer calculation which includes all orders of multiple scattering and absorption by ozone then gives the direct and diffuse components of solar flux incident on the cloudtops or, for clear skies, on the ground.

The downward diffuse flux, $F^{\downarrow}(\lambda,\theta,\tau)$, for a wavelength λ, solar zenith angle θ, and optical depth τ, can be expressed as the sum of an atmospheric scattering component $F_a^{\downarrow}(\lambda,\theta,\tau)$ and a contribution arising from downward scattering of radiation that has already been reflected from the lower boundary (Dave and Furukawa, 1966).

$$F^{\downarrow}(\lambda,\theta,\tau) = F_a^{\downarrow}(\lambda,\theta,\tau) + Q(\lambda,R,\tau^*)F_g^{\downarrow}(\lambda,\theta,\tau) \qquad (1)$$

where:

$$Q(\lambda,R,\tau^*) = R \,/\, [1-RS(\lambda,\tau^*)] \qquad (2)$$

Here τ^* is the atmospheric optical depth above the reflecting surface (ground or cloudtop) of albedo R, $S(\lambda, \tau^*)$ represents the backscattering power of the atmosphere, and $F_g^{\downarrow}(\lambda, \theta, \tau)$ measures the contribution from flux that has already reflected from the lower boundary and is then scattered back into the lower hemisphere. The advantage of the formulation in equations 1 and 2 is that the quantities $F_a^{\downarrow}$, $F_g^{\downarrow}$, and S can be computed without knowledge of the surface albedo. In practice, we calculate these terms using the Herman and Browning (1965) clear sky, multiple Rayleigh scattering model.

For clear sky conditions the formulation summarized above produces the UV-B and UV-A flux at the ground as a function of wavelength, solar zenith angle (local time), and ozone amount. Under cloudy sky conditions, however, we must define the transmission and reflectivity of the cloud-subcloud-ground layer. For this we use a two stream radiative transfer model coupled with the "adding method" for a multi-layer atmosphere developed by Lacis and Hansen (1974). This approach divides the atmosphere into a series of homogeneous layers where each layer has a known reflectivity and transmission. Clouds occupy the uppermost layers, while the bottom layer is the ground with a transmission of zero. The composite reflectivity and transmission of the multilayer system is determined by combining the reflectivities and transmissions of the individual layers with proper account taken of multiple reflections of upward and downward directed fluxes. Lacis and Hansen (1974) have presented quantitative details of the technique. The model adopts fractional cloudcover as a function of latitude from Hughes (1984). We assume a mixture of thick low clouds, with an optical depth for scattering of 30, and middle level clouds of optical depth 15 (Stephens, 1978). We assume cloud drops to be non-absorbing in the UV-B and UV-A. However, absorption of radiation still occurs in the clouds owing to the tropospheric ozone amount included in the model. The calculations assume that 85 percent of the downward radiation incident at the cloudtops is scattered into the lower hemisphere. The derived transmission of the cloud-subcloud system multiplied by the total (direct plus diffuse) flux incident on the cloudtops from equation 1 gives the flux at the ground. Note that we assume all radiation transmitted through the cloud to be isotropic over the lower hemisphere, consistent with a large optical depth for scattering.

The reflectivity and transmission of atmospheric layers beneath the cloud deck are defined by expressions for a two stream model as given by Coakley and Chylek (1975) and Joseph et al. (1976). Each layer has a known optical depth and an ozone amount based on climatology supplied with the SBUV data set. To obtain the flux at the ground for a climatological fractional cloudcover, we simply combine values derived separately for clear and cloudy skies using the weights 1-f and f respectively, where f is the fractional cloudcover at the latitude of interest.

In principle one could compute the UV-B and UV-A fluxes at the ground using a complete radiative transfer calculation for any combination of wavelength, ozone abundance, cloudcover, solar zenith angle, and ground reflectivity. In practice this is not necessary. Instead we generated three sets of flux tables, one with the base of the clear atmosphere at 1000 mb, another at 700 mb, and the last with the base at 400 mb. Each table contains the radiative transfer quantities of equations 1 and 2 for 23 wavelength bands which span the wavelength range 290 to 400 nm, 9 total column ozone amounts, and 13 solar zenith angles. Surface reflectivities corresponding to the ground or cloudtops need not enter the tables in view of the form of equation 1. Each table allows interpolation to obtain surface fluxes for any ozone value and local time, while a combination of all three tables provides fluxes for varying terrain heights and cloudcover conditions. This flexibility allows the algorithm to predict the ultraviolet radiation environment at any location on the globe for any time of year by interpolation based on precomputed radiation tables. Surface fluxes may refer to specific local times or to averages over the daylight period at any location and date.

III. The Input Data Sets

The SBUV instrument provides the total column ozone and vertical ozone profiles needed to evaluate terms in the radiative transfer calculations. We use SBUV column ozone amounts averaged over one month time intervals and over all longitudes in 10 degree wide latitude bands. We associate these means with the center of each month and latitude bin. Interpolation in latitude and time then provides the ozone amount for a specific location and day of the year. Figure 1 illustrates the behavior of column ozone as a function of latitude and month derived from SBUV. We note that a very recent revision in the SBUV data set uses improved absorption cross sections and yields values approximately 6% greater than those shown in Figure 1. The current version of the global radiation algorithm uses the updated ozone results. The extraterrestrial solar irradiance, ozone absorption cross sections, and Rayleigh scattering cross sections used in the calculations are from Chapter 7 of WMO/NASA (1986).

IV. Algorithm Operation and Sample Results

The algorithm allows the user a high degree of flexibility in selecting parameters for a given calculation. Mandatory inputs supplied by the user are: (1) latitude and longitude, (2) day number of the year, 1 through 365, and (3) local time. As an alternative to local time the user can choose to compute mean fluxes over the daylight portion of a 24 hour period. Given these inputs the algorithm chooses a zonal mean ozone value based on the SBUV data set, a terrain elevation and ground albedo from Kalnay et al. (1983), and zonal mean fractional cloudcover from Hughes (1984). The ultraviolet flux at the ground as a function of wavelength is then obtained by interpolation from the precomputed tables for clear and cloudcovered conditions. The user can also circumvent the data sets built into the algorithm and enter a total column ozone value, terrain elevation, ground albedo, and fractional cloudcover suited to any location of interest.

As an illustration of the algorithm's capability, Figure 2 presents the latitudinal and monthly distribution of UV-B radiation at the surface of the Earth for clear sky conditions. Contours in the figure are in watts per square meter and are based on the ozone values of Figure 1. All values refer to a local time of 10:00 A.M. and represent the sum of all radiation at wavelengths between 290 and 320 nm. In practice, radiation at wavelengths less than 290-295 nm makes a negligible contribution to the total UV-B. The largest fluxes, 4 watts per square meter, reach the ground in the tropics because the sun is most nearly overhead here, and the atmospheric ozone amounts are relatively small. The major feature of Figure 2 is the large variation in radiation flux with latitude, especially during the winter season. In the Northern Hemisphere for December and January the flux decreases by a factor of 10 between the equator and 50 degrees latitude. During summer the latitudinal gradients are much less pronounced than in winter, and one must move from the tropics to 60 degrees to experience a factor of two decrease in flux at the ground. There is very little change in the 10:00 A.M. fluxes in the tropics over the course of a year. At middle latitudes, however, the seasonal cycle can range between a factor of two and ten depending on location.

A calculation analogous to that in Figure 2 could be done for the UV-A spectral region. Although the contours would be similar in shape, the gradients would be much less pronounced because of the greatly reduced absorption by ozone at wavelengths longward of 320 nm. Figure 3 illustrates this behavior by giving contours of the ratio of UV-B to UV-A fluxes as a function of latitude and month at a local time of 10:00 A.M. Clearly, the UV-B flux is much smaller than the UV-A, with the ratio ranging from 2 to 7.5%. The most significant information in Figure 3 is the differing latitudinal and seasonal gradients shown by the UV-B and UV-A. As one moves from the tropics to 60 degrees latitude in winter, the UV-B flux decreases more rapidly than the UV-A by a factor of three to four. In summer the relative variation is much less than a factor of two.

The examples presented above illustrate latitudinal and seasonal variations. Future updates of the algorithm for use in truly global studies should include longitudinal variations in both fractional cloudcover and ozone. For many applications, however, the focus is on the radiation environment at a specific location as well as on changes in dose rates with parameters such as the ozone amount and fractional cloudcover. A separate report by H. Pitcher and J. Scotto now in preparation will describe such studies, including the comparison of model predictions with ground-based measurements from Robertson-Berger meters.

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List of Figures

Figure 1. Contours of total column ozone (milli-atmosphere-centimeters) as a function of latitude and month derived from the SBUV instrument.

Figure 2. The latitudinal and monthly distribution of UV-B radiation at the ground computed for clear sky conditions and a local time of 10:00 A.M. Contour values, in watts per square meter, include all wavelengths between 290 and 320 nm.

Figure 3. The ratio of solar energy flux in the UV-B from Figure 2 to that in the UV-A (320-400 nm) as a function of month and latitude. Values refer to radiation reaching the ground for 10:00 A.M. local time and clear sky conditions. Contours are in percent (7.5 means that the UV-B energy flux is 7.5% of that in the UV-A).

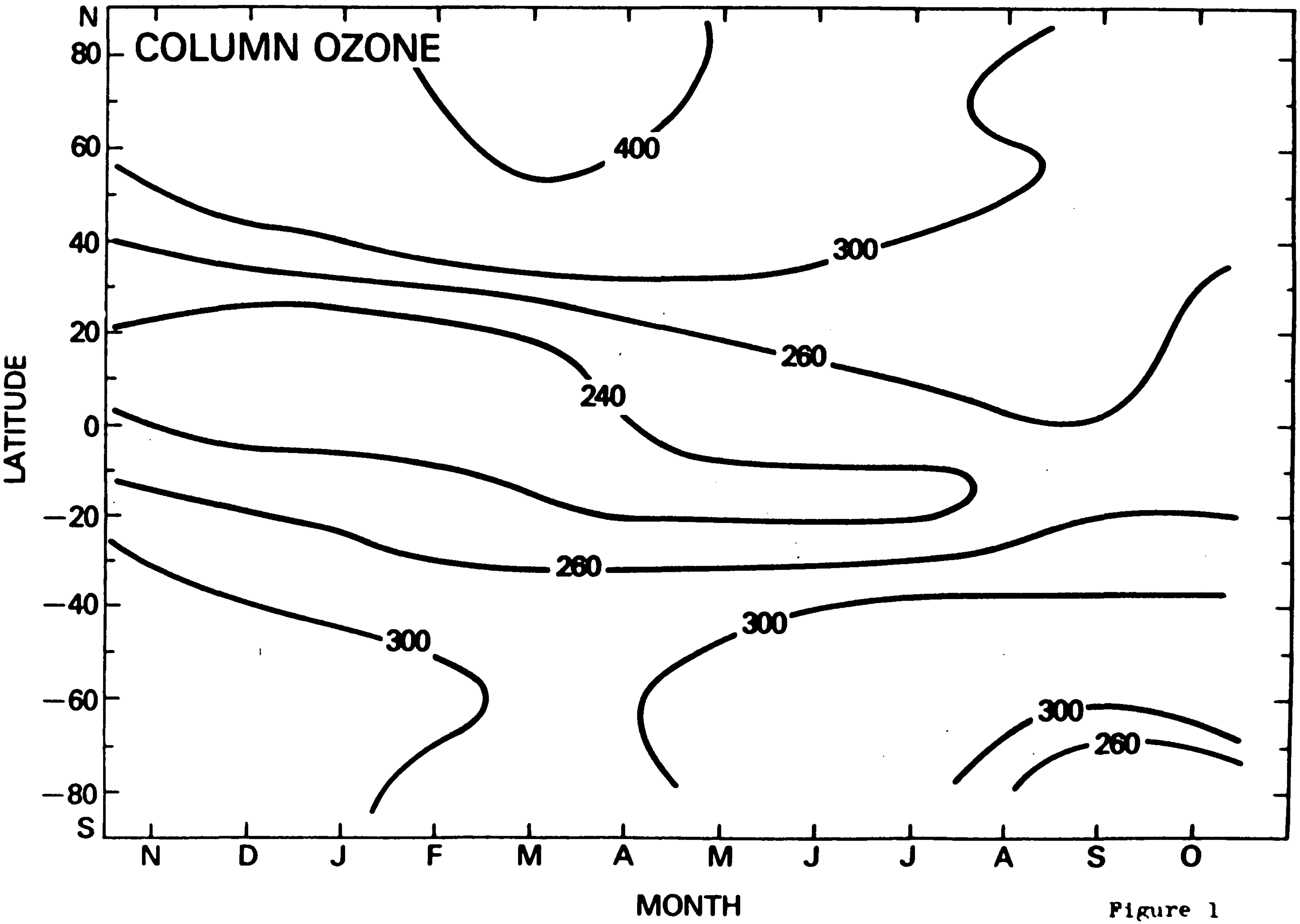

COLUMN OZONE
N
80
60
40
20
0
-20
-40
-60
-80
S
LATITUDE
400
300
260
240
260
300
300
300
260
N
D
J
F
M
A
M
J
J
A
S
O
MONTH

Figure 1

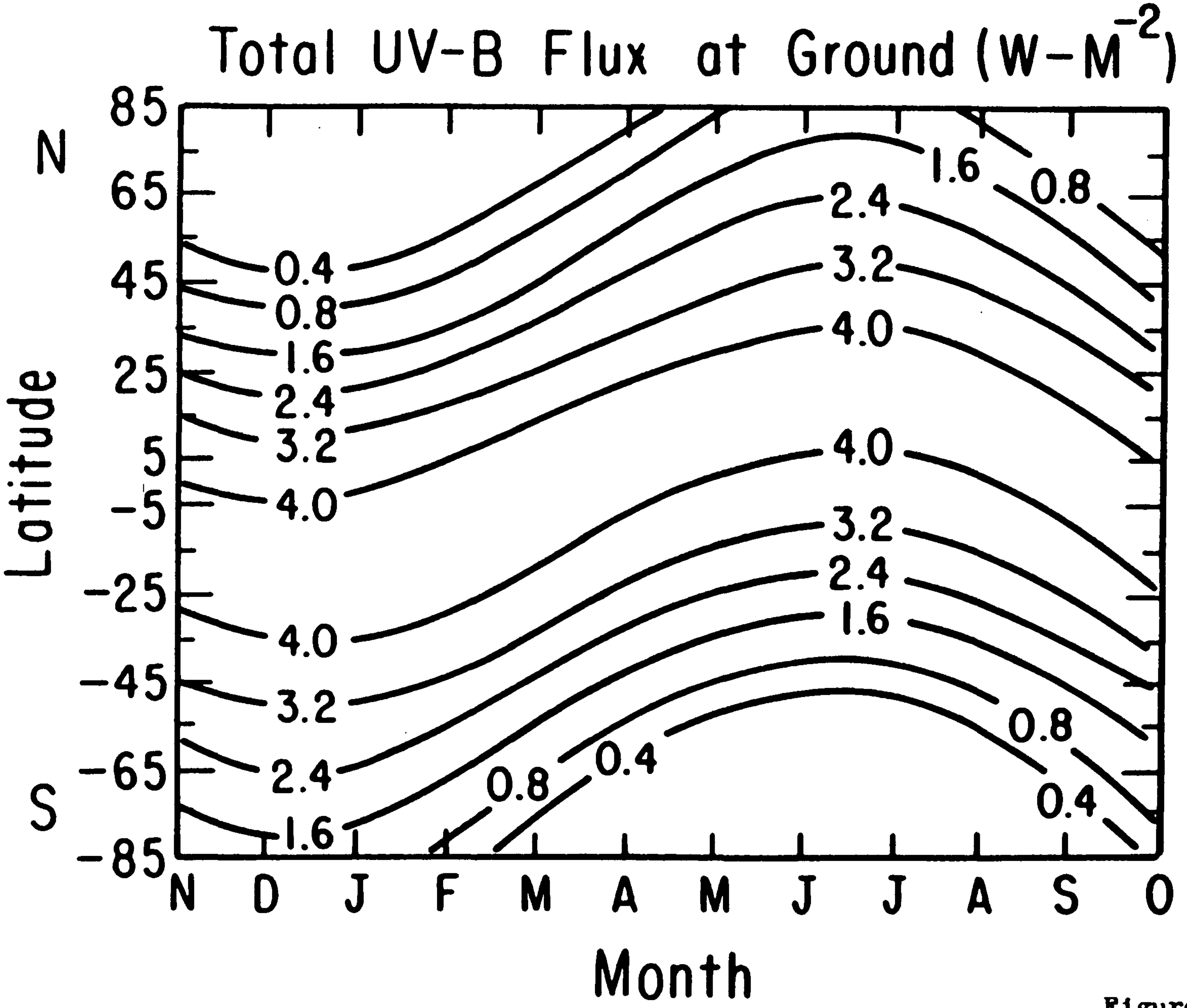
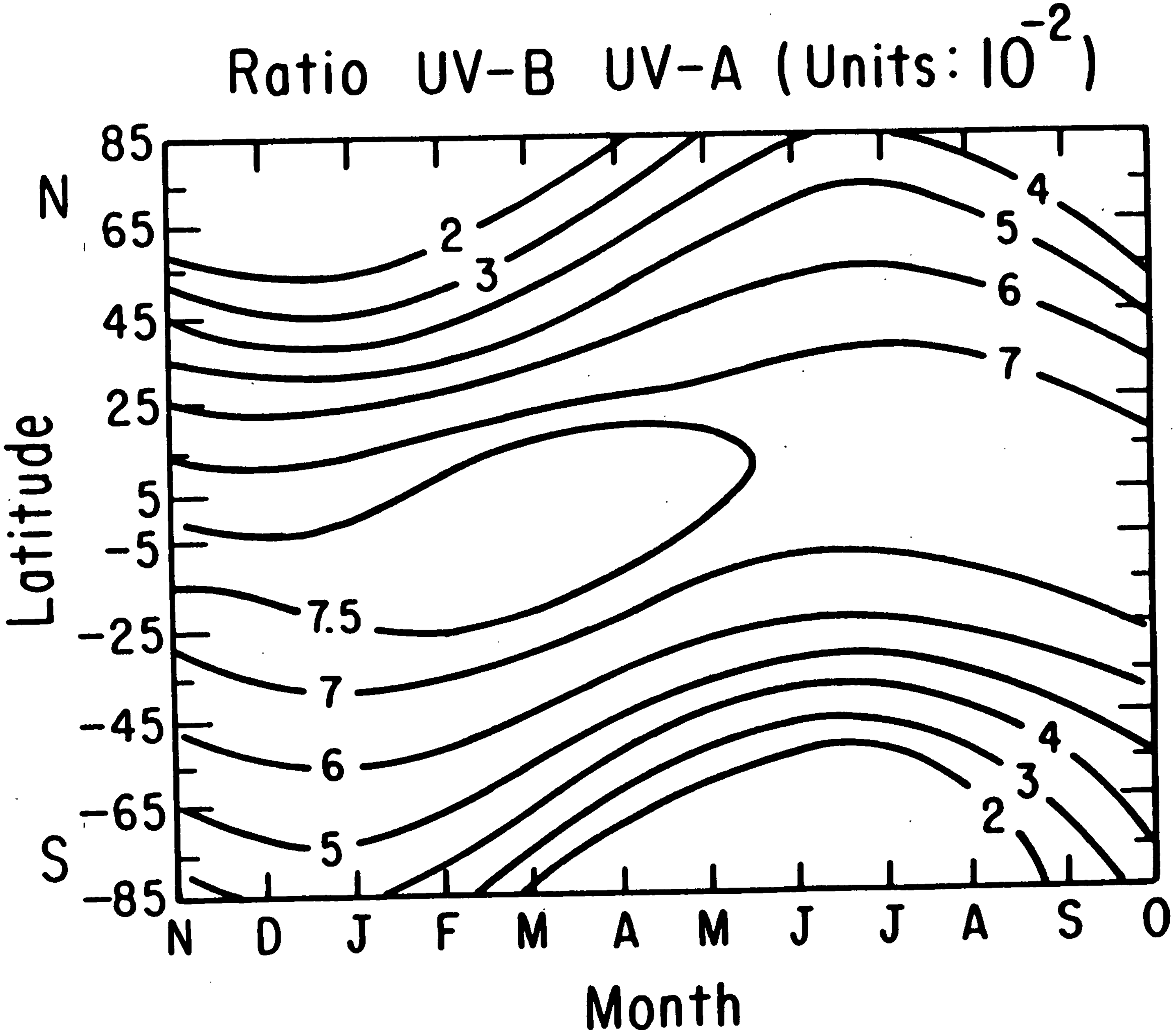

Total UV-B Flux at Ground (W-M^-2)
85
N
65
45
25
5
-5
-25
-45
-65
S
-85
Latitude
N D J F M A M J J A S O
Month
0.4
0.8
1.6
2.4
3.2
4.0
4.0
3.2
2.4
1.6
0.8
0.4
2.4
3.2
4.0
1.6
0.8
4.0
3.2
2.4
1.6
0.8
0.4

Figure 2


Ratio UV-B UV-A (Units: 10^{-2})
Latitude
N
S
85
65
45
25
5
-5
-25
-45
-65
-85
Month
N D J F M A M J J A S O
2
3
4
5
6
7
7.5
7
6
5
4
3
2
Figure 3

IMPORTANT NOTE TO READERS

EPA has submitted a draft document, An Assessment of the Risks of Stratospheric Modification, to the Science Advisory Board today (October 23, 1986), and also has released it for public review and comment. On November 24 and 25 the Science Advisory Board, chaired by Dr. Margaret Kripke of The University of Texas Department of Immunology, will meet to review the document.

Until the SAB review is completed and the document revised, the Assessment will not represent the official views of EPA. The estimates of risks in the document and the numbers contained in it should be viewed as preliminary, and EPA requests that they not be cited or quoted.

The document contains no recommendations for risk management actions. Rather, it is a compilation of scientific assessments of risks. When reviewed and revised it will serve as the basis for EPA decisionmaking. Thus the review that is now being initiated is solely a scientific review.

The Assessment builds on the atmospheric assessments conducted by the World Meterological Organization, NASA, NOAA, CMA, and other national and international scientific organizations. Much of this previous work has already been peer reviewed.

The Assessment covers and integrates information in a variety of areas: industrial emissions of trace gases that can modify the stratosphere; biogenic emissions of such gases; possible changes in atmospheric concentrations which may occur in response to these atmospheres; the response of ozone in the stratosphere to these changes; the response of the global climate system to stratospheric modification and trace gas build up; basal and squamous skin cancers; melanoma; immune suppression by ultra-violet radiation;crop and terrestial ecosystem effects; aquatic systems effects; the effects of UV-B on polymers; the effects of UV-B on tropospheric air quality; sea level rise; and the effects of climate change.

In some cases qualitative assessments are made of these impact areas; in other cases quantitative estimates are made. In all cases, uncertainties are identified and their ramifications examined. An effort is made to examine how these areas are linked together so that the risks can be examined over time.

The general conclusion of the Assessment as it now stands is that a number of health and welfare impacts are likely if emissions of chlorofluorocarbons grow. A variety of uncertain factors are found to be important in determining the magnitude of likely effects, including: the future growth of greenhouse gases that could warm the earth which would counter ozone depletion; the exact dose-response relationships for health effects; the rate of chlorofluorocarbons and halon growth; and the actual response of the atmosphere to changes in trace gases. As it now stands the Assessment uses conventional atmospheric chemistry in assessing risks, arguing that too little is understood about the Antarctic ozone hole to use it to re-evaluate current models of the rest of the world.

The reviewed and revised Assessment will serve as a basis for decisionmaking in EPA's regulatory program. EPA is scheduled to make a proposal which suggests regulations or states there is no need for regulation on May 1,1987 and to make a final regulatory decision November 1, 1987. In addition, international negotiations are underway under the United Nations Environmental Programme to develop a protocol to limit chlorofluorocarbons globally.

For additional information call:

John S. Hoffman
Chairman,Stratospheric Protection Task Force
EPA,PM-221
401 M Street, SW
Washington, DC 20460
(202) 382-4036