pls. file w/ ozone
stuff —
1994
Scientific
Assessment.

FACSIMILE COVER SHEET

AERONOMY LABORATORY
NOAA, Mail Code R/E/AL
325 Broadway
Boulder, Colorado 80303

DATE: 17 Nov 91

PAGES: Cover and 1 pages to follow.

FROM:

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TO:

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ADDITIONAL COMMENTS:

Katie, Mike, & Tony - Thanks for your help in setting up the hearing Friday. There was a good turn-out, wasn't there?

For your info, should it prove useful, I tried to get all of the key points of the UNEP report distilled to one page, which I attach.

Do let Bob or I know if we can help with any other information.

Best, Dan

"SCIENTIFIC ASSESSMENT OF OZONE DEPLETION" POLICY-RELEVENT MAJOR POINTS: AT-A-GLANCE

17 November 1991

Background

(1) The following conclusions are from a new WMO/UNEP scientific report. It will be used as input to the Montreal Protocol and to the IPCC updates in 1992. A synthesized Executive Summary of the science, effects, and technical-options reports will be prepared within the next few weeks.

Ozone Layer Depletion

(2) The human cause of the Antarctic ozone hole is now even more scientifically certain. Laboratory, further analyses of field data, and modeling are now more quantitative, with fewer "loose ends".

(3) Latest data indicate larger decadal ozone losses globally. For example, the midlatitude-winter decadal loss rate over the recent period 1979 - 1991 is 4.7 ± 0.7 %, compared to 2.7 ± 0.7 % for the longer period of 1970 - 1991. The independent 11-yr satellite data set and the 34-yr ground-based data set are in good agreement.

(4) Global ozone depletions are now observed in spring and summer. For example: the May-August periods from 1979 - 1991 shows 3.3 ± 1.2% loss per decade at midlatitudes. Earlier studies had found downward trends at midlatitudes only in the winter periods.

(5) Ozone losses are confirmed to be occurring in the *lower* stratosphere. The location of these losses is what introduces the link between ozone depletion and greenhouse radiative "forcing".

Greenhouse Radiative Forcing

(6) Preliminary picture: Ozone losses cause a *tendency* toward "climate cooling". Here's why...
> Ozone losses predicted to cause a *local* cooling in lower stratosphere.
> Such a local cooling would radiate less heat toward the surface.
> Less heat input yields a tendency for a cooler lower-atmosphere/surface system.

(7) This *indirect* cooling tendency may offset the *direct* warming tendency predicted for the ozone depleters. These are CFCs (largely), methyl chloroform, Halons, and other man-made gases.

(8) As a result, CFCs may drop in importance as greenhouse gases (but not as ozone depleters). Hence, other greenhouse gases are larger percentages of the total greenhouse radiative forcing.

(9) The total radiative forcing is probably somewhat overestimated. The predicted past (and future) greenhouse forcing may be ~20% less than that stated in earlier calculations (e.g., IPCC).

(10) Important near-term research is needed. Global Circulation (climate) Models are being run with lower-stratospheric ozone losses and ozone-depleting greenhouse gas increases, which will better describe the *net* effect of the predicted local lower-stratospheric cooling on surface climate.

Global Warming Potentials (GWPs) and Comprehensive Approach

(11) GWPs are more difficult to calculate reliably. The WMO/UNEP report will NOT give *indirect* components of GWPs. Many gases are known to have both. Example: methane is itself a greenhouse gas (direct), but it also influences other greenhouse gases, like water vapor (indirect).

(12) The GWP concept is solid, but harder to implement in near term. Indirect components cannot be calculated as reliably as was thought in IPCC.

(13) Future research plans:
> Improved GWP (direct and indirect) for methane in a few months.
> Improved *net* GWPs for each ozone depleter in mid-to-late 1992.
> No reliable GWPs for "air-pollution" species in near future.

UNITED NATIONS
ENVIRONMENT PROGRAMME

ENVIRONMENTAL EFFECTS OF OZONE DEPLETION: 1991 UPDATE

Introduction
Executive Summary

Panel Report Pursuant to Article 6 of the Montreal Protocol
on substances that Deplete the Ozone layer
under the Auspices of the
United Nations Environment Programme (UNEP)

November 1991

INTRODUCTION

ENVIRONMENTAL EFFECTS OF OZONE DEPLETION

The Montreal Protocol on Substances that Deplete the Ozone Layer requires in Article 6 periodic assessments of available scientific, environmental, technical and economic information. The assessments shall be made every four years.

The latest assessments were made in 1989. For the reconsideration of the agreements in the Montreal Protocol in 1992, UNEP decided that the 1989 assessments would be updated, rather than making completely new ones. The present report is such an update of the 1989 Environmental Effects Panel Report. It focuses, therefore, on developments since 1989. Information covered in the previous report that is still up-to-date is not repeated. For this reason, the chapters of this update include the summary of the corresponding chapter in the 1989 Report.

The occasion calls for an evaluation of how research on effects of increased UV-B radiation has proceeded during the past years. We cannot conceal that progress is disappointing. Many of the "Research Needs" formulated in previous reports have to be listed again. The scientific community has followed some of the recommendations, but by no means all. Urgent problems are still waiting to be addressed.

The underlying cause has been signalled over many years by the UNEP Co-ordinating Committee on the Ozone Layer. Funding for research on the consequences of increased UV-B radiation is disproportionately low, typically less than 1 percent of what is made available for atmospheric research in relation to ozone depletion. This comment is still valid. There is improvement of funding in some countries, but this is counterbalanced by a decrease in other countries. Several research groups, having contributed important information for previous assessments, have even ceased to exist. Effects research is necessary to provide policy makers with relevant information, so that they may evaluate response strategies to future challenges. The possibility to do this in a timely fashion may well depend on the funding situation.

Increased UV-B radiation will have many effects on man, animals, plants, and materials. For several potentially important effects, our Panel could do no more than express its concern; more knowledge is needed to come to firm conclusions. The deleterious effects that we recognize are serious enough to plea for action by the nations of the world to protect the ozone layer.

J.C. van der Leun
M. Tevini

EXECUTIVE SUMMARY

SOLAR INTERACTIONS

- Significant global scale decreases in total ozone have occurred over the past ten years.
- All other factors being constant, there is no scientific doubt that decreases in total ozone will increase UV-B radiation at ground level.
- Tropospheric ozone and aerosols may have masked the consequences of stratospheric ozone depletion for UV-B in some industrialized regions.
- It is likely that in areas remote from anthropogenic emissions, the UV-B changes due to stratospheric ozone depletion would be only partially compensated by tropospheric ozone and aerosol increases.
- There are no reliable estimates of the direction or magnitude of effects of any cloud cover trends on UV-B.
- Efforts to improve local and regional air quality may bring to light the increases in UV-B associated with the depletion of stratospheric ozone.

HEALTH

- The induction of immunosuppression by UV-B has now been demonstrated in humans, not only those of light pigmentation, but also deeply pigmented individuals.

  This places all of the world's populations at risk of the potential adverse impacts of UV-B on the immune system, including possible increases in the incidence or severity of infectious disease.

- An increased number of adverse ocular effects have been associated with exposure to UV. These include age-related nearsightedness, deformation of the lens capsule, and nuclear cataract (a form of cataract which previous information excluded from consideration). These effects appear to be independent of pigmentation. Including nuclear cataract among the forms of cataract likely to increase with ozone depletion enlarges slightly the risk estimates. It is now predicted that, all other things being equal, a sustained 10% decrease in ozone will be associated with between 1.6 and 1.75 million additional cases of cataract per year world-wide.
- Recent information on the relationship of non-melanoma skin cancer to UV exposures confirms previous findings and has allowed refinement of the carcinogenic action spectrum. Incorporation of this new information into the risk estimation process has led to slightly lower predictions. It is now predicted that a sustained 10% decrease in ozone will be associated with a 26% increase in non-melanoma skin cancer. All other things remaining

constant, this would mean an increase in excess of 300,000 cases per year worldwide.

TERRESTRIAL PLANTS

- Continued research on plant responses to UV-B radiation underscores the concern for agriculture, forestry, and natural ecosystems as the ozone layer is depleted.

- Growth and photosynthesis of certain plants (e.g., seedlings of rye, maize, and sunflower) can be inhibited even under ambient levels of UV-B radiation.

- Certain environmental factors, both biotic (e.g., plant diseases and competition with other plants) and abiotic (e.g., carbon dioxide, temperature, heavy metals, and water availability), can interact with the effect of UV-B radiation in plants. This makes it difficult to make quantitative predictions.

- Although most research to date has been with plants from temperate regions, data also show that certain tropical species may be adversely affected by enhanced UV-B radiation.

AQUATIC ECOSYSTEMS

- Marine phytoplankton produces at least as much biomass as all terrestrial ecosystems combined.

- Recent results show that the aquatic ecosystem is already under UV-B stress and there is concern that an increase in UV-B radiation will cause detrimental effects.

- One consequence of losses in phytoplankton is reduced biomass production which is propagated throughout the whole food web. This may result in losses of biomass for human consumption.

- The marine phytoplankton is a major sink for atmospheric carbon dioxide. Any reduction of the populations would decrease the uptake of carbon dioxide and so augment the greenhouse effect. Also, phytoplankton production of DMS (dimethylsulphate), which acts as a precursor of cloud nucleation, would be reduced, hence potentially affecting global climate.

- A UV-B induced decrease in microorganisms fixing atmospheric nitrogen would require significant substitution by artificial fertilizers, e.g., in rice production.

TROPOSPHERIC AIR QUALITY

- Chemical reactivity in the troposphere is expected to increase in response to increases in UV-B.

- Tropospheric ozone concentrations could rise in moderate to heavily polluted areas, but should decrease in unpolluted regions (with low oxides of nitrogen levels), as recently

confirmed by measurements in the Antarctic.

- Other potentially harmful substances (hydrogen peroxide, acids, and aerosols) are expected to increase in all regions of the troposphere due to the enhanced chemical reactivity.

- These changes could exacerbate problems of human health and welfare, increase damage to the biosphere, and might make current air quality goals more difficult and expensive to attain.

MATERIALS DAMAGE

- UV-B radiation is particularly effective in light-induced degradation of wood and plastic products, leading to discoloration, and loss of strength. Increased UV-B content in sunlight will cause more rapid degradation, resulting in increased costs of using higher levels of conventional light stabilizers, possible design of new stabilizers, and faster replacement of the affected products.

- Available research data are inadequate to reliably estimate the damage from higher UV-B levels to materials. Very limited relevant data are available for important classes of materials such as wood, plastic coatings, plastics used outdoors, and rubber. Data pertaining to performance of plastics in near-equator regions of the world, with the harshest exposure environments, are particularly needed.

- Some on-going work relating to exposure of plastics under desert conditions is likely to contribute some of the needed data within the next few years. This may lead to improved assessment of damage to plastics resulting from partial ozone depletion, at that time.

KEY AREAS OF UNCERTAINTY

The key areas of uncertainty are the following:

- Quantification of the primary effects on food production and quality, on forestry, and on natural ecosystems.

- Clarification and quantification of influences on human health, especially the immune system, and occurrences of melanomas and cataracts.

- Effects on biota of the enhanced UV radiation during the Antarctic springtime ozone depletion.

The report on Environmental Effects of Ozone Depletion *was prepared by an international group of scientists. The chairman of the group was Dr. Jan C. van der Leun (The Netherlands), and the co-chairman was Dr. Manfred Tevini (Federal Republic of Germany).*

Katell

WMO/UNEP

OZONE SCIENCE

PEER REVIEW MEETING

OCTOBER 14-18, 1991

Les Diablerets, Switzerland

CHAPTER SUMMARIES

6:00 PM 18 OCT 1991

Ph. Jelenski
ozone -
Scientific assessment

Chapter 1 Source Gases: Concentration, Trends and Emissions.

- The major anthropogenic source gases implicated directly in halogen induced stratospheric ozone loss, i.e., CFCs, HCFC-22, the halons, methyl chloroform and carbon tetrachloride, continue to grow in concentration in the background troposphere of both hemispheres. Total tropospheric chlorine is increasing by 0.1 ppbv per year. CFCs contribute approximately 75% to this increase, methyl chloroform about 13% and HCFC-22 about 5%. The data are summarized in the following table:

Species	Annual Mean Concentration (pptv), 1989	Trend (pptv/yr) 1987 WMO (1990)	Trend (pptv/yr) 1989 WMO (1992)	Calibration Uncertainty Range (%)	Calibration Change Since WMO (1990)
CFC-11	255 [a]	9 - 10	9 - 10	4	-
CFC-12	453 [a]	16 - 17	17 - 18	4	-
CFC-113	64 [a]	5	6	10	+12%
CCl_4	107 [a]	2	1 - 1.5	10	- 20%
HCFC-22	110	7	5 - 6	20	-
CH_3CCl_3	150 [a, b]	6	4 - 5	20 [c]	-
$CBrClF_2$	1.8 - 3.5	0.2	0.4 - 0.7	80	-
$CBrF_3$	1.6 - 2.5	0.3	0.2 - 0.4	30	-

a - based on GAGE data
b - the 1987 mean CH_3CCl_3 concentration was 140 pptv, not 150 pptv as reported in WMO (1990).
c - the data reported are at the high extreme of the range.

- A significant oceanic sink has been identified for methyl chloroform, which implies 5-10% lower average hydroxyl radical levels calculated using methyl chloroform data. Calibration studies indicate that the methyl chloroform concentrations and trends may be 10% lower, implying 10% higher hydroxyl radical levels derived using the same method. These variations are well within the uncertainty of the rate of methyl chloroform - hydroxyl radical reaction (±20%).

- The methane growth rate continues to decline from ≈20 ppbv/yr in the late 1970s to ≈13 ppbv/yr. in 1989. No satisfactory explanation of this phenomenon has emerged. Ice core studies indicate that methane growth rates have shown significant temporal variability over the past 100 years.

- Recent methane isotopic studies suggest that approximately 20% of the total methane source (500 Tg/yr) is fossil, largely from the coal, oil, and natural gas industries, and 10% is from biomass burning.

- Recent studies on methane emissions from tropical rice agriculture show large variations and the overall uncertainty of the magnitude of this source remains large. Indian studies suggest that the global methane source from rice agriculture may be significantly lower than 100 Tg/yr.

- Nitrous oxide continues to increase globally at about 0.8 ppbv/yr. New global nitrous oxide sources have been proposed [adipic acid (nylon) production, legume pastures], but the sum of all known sources is not sufficient to balance the calculated atmospheric sink.

- Carbon monoxide levels are growing in the northern hemisphere at 0.8 ± 0.4 ppbv/yr, but there has been no increase observed in the southern hemisphere.

- Methyl bromide is the major source of stratospheric bromine. While the possibility of a trend in methyl bromide cannot be assessed due to lack of data, a large anthropogenic methyl bromide source has been previously suggested.

MEASURED TRENDS IN OZONE AND TEMPERATURE

Observational Record: Since the 1989 assessment the observational record includes an additional 2.5 years of Dobson, SAGE, and TOMS data and a complete re-analysis of 29 ground-based M-83/124 stations in the USSR. This is complemented by a major new advance in the observational record of an internally calibrated TOMS data set that is now independent of ground-based observations. Trend analyses of SAGE data have been extended to the lower stratosphere and the Umkehr data have been reanalyzed.

Antarctic Ozone: The Antarctic ozone hole in 1991 was as deep and as extensive in area as those of 1987, 1989, and 1990. The low value of total ozone measured in 1991 was 110 Dobson Units, a decrease of 60% compared to ozone levels prior to the late 1970s. The previously noted quasi-biennial modulation of the severity of the ozone hole did not occur during the last three years. The area of the ozone hole was similar for these 4 years.

Trends in Total Ozone: Ground-based (Dobson and M-83/124) and satellite (TOMS) observations of total column ozone through March 1991 were analyzed allowing for the influence of solar cycle and quasi-biennial oscillation (see table). They show that:

(a) the northern mid-latitude winter and summer decreases during the 1980s were larger than the average trend since 1970 by about 2% /decade. A significant longitudinal variance of the trend since 1979 is observed.

(b) for the first time there are statistically significant decreases in all seasons in both the northern and southern hemispheres at mid- and high-latitudes during the 1980s; the northern mid-latitude long-term trends (1970-91), while smaller, are also statistically significant in all seasons.

(c) there has been no statistically significant decrease in tropical latitudes from 25°N to 25°S.

Trends in the Vertical Distribution of Ozone: Balloonsonde, ground-based Umkehr, and satellite SAGE observations show that:

(a) ozone is decreasing in the lower stratosphere, i.e., below 25 km, at about 10%/decade, consistent with the observed decrease in column ozone.

(b) changes in the observed vertical distribution of ozone in the upper stratosphere near 40 km are qualitatively consistent with theoretical predictions, but are smaller in magnitude.

(c) measurements indicate that ozone levels in the troposphere, over the few existing ozone sounding stations at northern mid-latitudes, have increased about 10%/decade over the past 2 decades.

Trends in Stratospheric Temperature: The temperature record indicates a small cooling (about 0.3°C per decade) of the lower stratosphere in the sense of that expected from the observed change in the stratospheric concentration of ozone.

Total Ozone Trends in %/decade with 95% confidence limits

	TOMS: 1979-1991			Ground-based: 26°N - 64°N	
	45°S	Equator	45°N	1979-1991	1970-1991
Dec-Mar	-5.2 ± 1.5	+0.3 ± 4.5	-5.6 ± 3.5	-4.7 ± 0.9	-2.7 ± 0.7
May-Aug	-6.2 ± 3.0	+0.1 ± 5.2	-2.9 ± 2.1	-3.3 ± 1.2	-1.3 ± 0.4
Sep-Nov	-4.4 ± 3.2	+0.3 ± 5.0	-1.7 ± 1.9	-1.2 ± 1.6	-1.2 ± 0.6

Scientific Summary, Chapter 3:

Heterogeneous Processes: Laboratory Studies and Atmospheric Observations

Since the previous assessment, there have been major advances in our understanding of the role of heterogeneous reactions on PSCs and stratospheric sulfate (H_2SO_4/H_2O) aerosols in increasing the abundance of active chlorine compounds in the lower stratosphere.

Reaction efficiencies: Direct chlorine activation (e.g. via $ClONO_2(g) + HCl(s) \rightarrow Cl_2(g) + HNO_3(s)$) is very efficient on surfaces which mimic PSCs. Denoxification (i.e., $N_2O_5(g) + H_2O(s) \rightarrow 2HNO_3(s)$) is very efficient on H_2SO_4/H_2O surfaces typical of mid-latitude stratospheric aerosols and indirectly enhances active chlorine by inhibiting formation of the reservoir $ClONO_2$. Direct chlorine activation on sulfate aerosols may also occur under volcanic conditions or at very cold temperatures, the latter becoming more important with expected future increases in stratospheric H_2O vapor. Furthermore, there may be other important heterogeneous processes that have not yet been identified.

PSC physical characteristics: Additional laboratory studies have confirmed that HNO_3/H_2O clouds can form above the frost point. Significant HNO_3 supersaturation may be required for Type 1 PSC formation, implying that heterogeneous processing by sulfate aerosols may be more important at lower temperatures than previously thought. Type 1 PSCs may exist in two subclasses which, in turn, may have different surface area characteristics and different heterogeneous processing efficiencies. HNO_3 has been shown to stick readily on pure ice and retards its sublimation, supporting the idea that falling ice crystals are responsible for stratospheric denitrification.

SAM II PSC climatology:

Antarctic: Average PSC sighting frequency peaks at about 60% near 18 km in August. Sighting frequency remains at 10-20% at lower altitudes - under dehydrated and denitrified conditions - well past the spring equinox. Individually or collectively, the high PSC frequency and persistence of the clouds into sunlit conditions provide firm evidence of a direct link between heterogeneous chlorine activation and South Polar ozone losses.

Arctic: Appreciable PSC sightings occur only from December through February, and the peak average sighting frequency is only about 10%. However, the limited spatial coverage of SAM II likely yields an underestimate of cloud frequency in the polar region as a whole. More robust PSC statistics will be required before the relationship between lower stratospheric ozone losses in the Northern Hemisphere and heterogeneous chlorine activation on Arctic PSCs can be quantified.

Stratospheric sulfate aerosols: Long-term observational records all show a 40-50% increase in loading over the decade from 1979 to 1989. The effective aerosol surface area available for heterogeneous chemical processing most likely increased by a comparable amount on a global scale during the same period. Additional loading from the June 1991 Mt. Pinatubo eruption will most likely be the greatest of the century to date (exceeding that of El Chichon) and is expected to persist for several years.

Heterogeneous processes must be included in stratospheric chemistry models. Measurements of ClO and HNO_3 are better explained by model calculations which include heterogeneous processing on PSCs and/or sulfate aerosols. Since there have been more extensive measurements of chemical changes in the polar regions, the picture of heterogeneous processing on PSCs is clearer. Direct heterogeneous chlorine activation in these clouds appears to be rapid and may not be dependent on detailed particle characteristics. Experimental opportunities provided by the Mt. Pinatubo injection should yield the data required to examine this issue more fully with regard to sulfate aerosols.

SUMMARY POINTS - CHAPTER 4
STRATOSPHERIC PROCESSES

- The primary cause of the Antarctic ozone hole is firmly established to be halogen chemistry. Increased confidence in this mechanism results from analyses using reevaluated field measurements, new laboratory data, and modeling studies.

- The year-to-year fluctuation in the area and depth of the ozone hole over the last decade, which has been attributed to dynamical affects, is not fully explained. The apparent lack of variability in recent years - extensive ozone holes have been observed in four of the last five years - may imply that halogen chemistry is becoming dominant over dynamical influences on Antarctic ozone depletion.

- High concentrations of ClO between 16 and 20 km have been observed in wintertime in the Arctic lower stratosphere. These observations have been incorporated into diagnostic models that have calculated localized ozone depletions of about 10% at these altitudes over a period of about a month, which are consistent with concurrent ozone measurements.

- Should an unusually cold and long winter occur in the Arctic polar vortex, the appearance of clearly detectable ozone depletions there will be more likely.

- Limited observations suggest that the abundance of ClO in the lower stratosphere at midlatitudes is greater than that predicted by current models containing only gas-phase chemistry, and the observed seasonal and latitudinal dependences are opposite to those predicted. Some new studies that incorporate currently known heterogeneous processes provide an improved simulation for some observed gases, such as ClO and nitric acid.

- There is not a full accounting of the observed downward trend in global ozone. Plausible mechanisms include heterogeneous chemistry on sulfate aerosols and the transport of chemically perturbed polar air to midlatitudes. Although other mechanisms cannot be ruled out, those involving catalytic destruction of ozone by chlorine and bromine appear to be largely responsible for the ozone loss and are the only ones for which direct evidence exists.

- The potential importance of ozone loss in the lower stratosphere due to bromine, through bromine-chlorine interaction, is significantly increased by the widespread enhanced ClO abundance.

- Because heterogeneous processes are important and the levels of chlorine in the stratosphere are increasing, volcanic injections into the stratosphere could have a substantial effect on global ozone.

- Increasing levels of atmospheric chlorine and bromine are expected to lead to significantly more ozone depletion.

Chapter 5. Tropospheric Processes.

Calculated O_3 changes. Models predict increasing tropospheric ozone in the Northern Hemisphere in response to increasing emissions of NOx, CO, CH_4 and NMHC. Model estimates of recent tropospheric trends are consistent with observations. Marked variations in ozone changes with latitude, altitude and season occur, which have to be taken into account if indirect climate effects are to be estimated.

Differences between model calculations of ozone increases from NOx emissions are large (~factor of 3). The spatial and temporal variations of the predicted ozone changes are particularly large, and the model results are highly sensitive to the background NOx concentration and the location of the emissions. Tropospheric aircraft produce ozone much more efficiently per unit emission than surface sources (by > a factor of 10). These factors preclude a globally-averaged quantitative assessment of O_3 formation from NOx emissions..

Differences between model predictions of O_3 increases in response to CH_4 emissions, and in the spatial distribution of these increases, are moderate (both within 50%). The sensitivity to background assumptions is also moderate, and estimates of ozone changes due to CH_4 emissions can be made.

Calculated OH changes. Increases in CH_4, CO and NMHC emissions lead to reduced OH values, while increased NOx emissions lead to enhanced OH levels. As a result of these opposing effects, the sign of future OH changes cannot be predicted. The indirect feedback effect of CH_4 emission on the tropospheric CH_4 concentration, through its effect on OH, is estimated to be ~+30%.

Indirect effects on GWPs. The indirect effects from CH_4 emissions on O_3 and CH_4 concentrations can be estimated with moderate accuracy. At present no estimates can be made of the indirect effects of NOx surface emissions, as uncertainties in the calculations are too large. Furthermore, the impact on O_3 and CH_4 from NOx emissions is in opposing directions.

Tropospheric chemistry of HCFCs and HFCs. The HCFCs and HFCs are primarily degraded by reaction with OH in the troposphere. Experimental studies show that the breakdown of the HCFCs and HFCs is generally as expected from analogy with the C_1 haloalkanes and alkanes. However, several of the intermediate oxidation products [for example, $C(O)FCl$, $C(O)F_2$, $CF_3C(O)F$, and, in the upper troposphere, the halogenated peroxyacyl nitrates], may have long lifetimes. Depending on their rate of uptake and hydrolysis in clouds and oceans, transport to the stratosphere could occur. This may influence the stratospheric ozone chemistry and radiation.

Uncertainties in present and future tropospheric OH concentrations lead to corresponding uncertainties in the HCFC and HFC lifetimes, and in the fractions of these compounds transported into the stratosphere. Emissions of HCFCs and HFCs will not perturb the tropospheric OH and O_3 chemistry.

Impact of increased emission on climatically-important gases and tropospheric lifetimes (τ) are:

Increased emission	OH	O_3	τ (CH_4, HCFC, HFC)
CH_4	-	+	+
NOx	+	+	-
CO	-	+	+
NMHC	-	+	+

Chapter 6. ODPs and CLPS

The recognition of the role of chlorine and bromine compounds in ozone depletion has led to the regulation of their source gases. Some source gases are expected to be more damaging to the ozone layer than others, so that scientific guidance regarding their relative impacts is needed for regulatory purposes. Parameters used for this purpose include the steady-state and time-dependent Chlorine Loading Potential (CLP) and the Ozone Depletion Potential (ODP). Chlorine loading potentials depend upon the estimated value and accuracy of atmospheric lifetimes and are subject to significant (order 20-50%) uncertainties for many gases. Ozone depletion potentials depend upon the same factors, as well as the evaluation of the release of reactive chlorine from each source gas and corresponding ozone destruction within the stratosphere.

ODPs have generally been calculated with two-dimensional numerical models, which have limitations in the treatments of atmospheric transport and chemistry required for evaluation of ozone losses. In particular, such models do not fully represent the transport processes of the lower stratosphere (so that the calculated release of reactive chlorine from the source gases there is subject to uncertainties) nor do they reproduce in detail the large observed ozone losses in the lower stratosphere, especially in polar regions. The sensitivity of modeled ODPs to these problems is reduced by virtue of the fact that the ODP is a relative parameter, but is not completely eliminated, so that the more conservative assessment parameter represented by the CLP has also been considered. In this assessment, ODPs are estimated both from models and using a new semi-empirical approach which uses measurements and/or deduced correlations between source gases (to evaluate reactive chlorine release) together with observations of ozone losses. A critical assumption in the semi-empirical approach is that observed lower stratospheric ozone losses are due to halogen chemistry. This assumption is well-justified in polar regions and likely to be largely true at mid-latitudes. Therefore, the semi-empirical ODPs are expected to be more realistic than those derived from current models, at least in polar regions.

Modelled steady-state ODPs and CLPs have been evaluated using improved kinetic schemes. Further, some preliminary model results include a treatment of known heterogeneous chemistry on mid-latitude sulfate aerosols. The numerical values of these modeled ODPs are close to those of previous assessments.

Semi-empirical steady-state ODPs are given for the polar lower stratosphere and, in a few cases, for the global average. The semi-empirical ODPs are generally larger than the modeled values for chlorocarbons whose stratospheric loss rates are slower than that of CFC-11 and smaller for those whose loss rates are faster than that of CFC-11. For example, for HCFC-22, the semi-empirical ODP is between about 20 and 80% greater than the range of the model values. For some Halons, the semi-empirical ODPs for polar regions exceed some model estimates by as much as a factor of two. For all of the HCFCs considered here, the inferred ODP values are well below the CLPs and show that the upper limit to ozone loss represented by the CLP is not realized in the stratosphere for these species. This narrows significantly the uncertainties in the ODPs for HCFCs.

During the next decade, stratospheric chlorine abundances are expected to rise substantially. This increase in chlorine will likely lead to further global ozone loss including larger reductions in the Arctic and perhaps in northern mid-latitudes. In this near-term period, the HCFCs and many Halons will have an impact that is considerably larger than their steady state ODPs, in some cases and over some time horizons by as much as a factor of two to five.

Chapter 7 RADIATIVE FORCING OF CLIMATE

Global Warming Potentials

Direct effects . Direct Global Warming Potentials (GWP) have been recalculated for tropospheric, well-mixed, radiatively active species (CH_4, N_2O and the halocarbons). We use updated lifetimes of these species and follow the same methodology as in IPCC (1990), for time horizons corresponding to 20, 50, 100, 200 and 500 years. The new GWP results indicate only modest changes from the IPCC (1990) values but there still exist uncertainties in these calculations due to uncertainties in the carbon cycle.

Indirect Effects. While chemical reactions involving the radiatively active atmospheric species can contribute to the GWPs, our ability to estimate them is restricted at present owing to complexities in the chemical processes and uncertainties in the temporal and spatial variations of various species. While the sign of the radiative forcing due to some of the indirect effects can be evaluated with a fair measure of confidence (Chapter 5), the quantitative aspects of the indirect effects are more difficult to ascertain than was anticipated earlier in IPCC (1990) and we do not recommend the use of those values.

Radiative forcing due to trace gases, including ozone (1980 - 1990)

Stratospheric Ozone. The observed ozone losses in the lower stratosphere cause a significant forcing of the climate system. The physical effects due to this loss consist of an increase in the solar and a decrease in the longwave forcing of the surface-troposphere system, together with a tendency to cool the lower stratosphere. The latter effect amplifies the longwave influences and can thus give rise to a significant net negative radiative forcing of the surface-troposphere system, but the magnitude of the induced forcing is very sensitive to the change in the lower stratospheric temperatures. This tendency is opposite to the direct positive (greenhouse) forcing exerted by the well-mixed gases and is pronounced in the mid-to-high latitudes of both hemispheres, and during all seasons. In fact, the magnitude of the negative ozone radiative forcing in these latitudes can be larger than the decadal greenhouse forcing due to the CFCs over this period, and could also be a significant fraction of the total decadal greenhouse forcing due to the non-ozone gases.

Tropospheric Ozone. Ozone in the troposphere, although present in smaller amounts than that in the stratosphere, has a significant opacity and exerts a greenhouse effect (positive forcing), with the sensitivity being greatest for ozone changes in the upper troposphere. However, the databases for tropospheric ozone trends are sparse and therefore inadequate for quantifying the global radiative influences due to tropospheric ozone changes.

Radiative forcing due to sulfate aerosols

Tropospheric Aerosols. Fossil fuel emissions over the past century have increased significantly the tropospheric sulfate aerosol concentrations. The contribution of this species to the direct clear-sky radiative forcing of the Northern Hemisphere is opposite to that due to the greenhouse gases and is estimated to be a significant fraction of the trace gas forcing. Although we are confident of the sign of the forcing, uncertainties exist owing to the spatial inhomogeneity of the aerosol distributions and a lack of understanding of the aerosol effects in cloudy regions.

Stratospheric Aerosols. With the eruption of Mt. Pinatubo in mid-1991, there is again a radiative forcing of the climate system due to increases in the concentrations of the stratospheric sulfate aerosols. These aerosols produce a net negative radiative forcing of the climate system which are comparable to the positive ones due to the greenhouse gases, but these forcings are short-lived. The presence of the aerosols in the stratosphere also contribute to a warming tendency in the lower stratosphere. Preliminary observations indicate about a 4 K warming of the tropical lower stratosphere two months following the Mt. Pinatubo eruption.

Chapter 8. Future Chlorine / Bromine Loading and Ozone Depletion (Fri 3 PM)

There has been a major advance in the 2-D assessment models used here: in addition to gas-phase photochemical reactions, most models now include currently known heterogeneous chemical reactions on the stratospheric sulfate layer. Further, three models also incorporate a parametric formulation of the chemistry involving polar stratospheric clouds (PSCs); but PSC simulations within a 2-D formalism are extremely difficult and remain controversial. Results are shown from these three types of models, denoted 'GAS', 'HET' and 'PSC', respectively. The only forcing considered in the model scenarios is the evolving atmospheric composition, which over the past decade, 1980-1990, has been dominated by the increase in halocarbon chlorine loading from 2.5 ppb to 3.6 ppb.

The 'GAS' models cannot explain the observed ozone losses over the decade 1980-1990 (see Table below and Chapter 2); calculated mid-latitude ozone losses are much less than observed over all seasons in both hemispheres.

The 'HET' models predict substantially greater ozone depletion with the addition of chlorine and bromine (than do 'GAS' models): in particular, O_3 in the lower, mid- to high-latitude stratosphere is 3 times more responsive to Cl_y and Br_y, while being 3 times less responsive to NO_y. Thus, for 'HET' models the increase in N_2O has a much smaller impact, but CH_4 increases (through the HO_x chemistry) become more important.

The 'HET' models explain most of the observed 1980-1990 trend in column ozone for the northern mid-latitudes in summer, but only about half of that in winter (see Table). The sensitivity to the sulfate-layer area is small, the predicted 1980-1990 trend increases, for example from -2% to -2.5%, when the area is increased a factor of 4 above background levels. (N.B. The sulfate layer was more than 4 times above background about half of the time between 1972 and 1989.)

The 'PSC' models predict still greater ozone loss at northern mid-latitudes in winter, in much better agreement with observations. However, both 'HET' and 'PSC' models must be verified and calibrated by detailed comparison with stratospheric observations (e.g., O3, CFCs, N2O, NOy, ClO); an international workshop is planned for February 1991.

TABLE. 1980-1990 Column Ozone Depletions
(ranges shown, all negative %)

	TOMS		'GAS'		'HET'		'PSC'	
	w	s	w	s	w	s	w	s
60N	6-8	3-4	1-2	1	3-4	3	5-7	3-4
30N	4-5	1-2	1	<1	2-3	1-2	2	1-2

w = Jan, Feb & Mar and s = Jul, Aug & Sep.

All models predict, as in previous assessments, a maximum depletion of 7-16% in ozone concentrations near 44 km altitude at 45N over the 1980-1990 decade. The lower values generally correspond to models that include temperature feedbacks which are expected when ozone decreases. These values are generally greater than observed, but just overlap with the uncertainties assigned to the measured trends.

We expect that atmospheric loading of chlorine and bromine will peak in the late 1990s at levels of about 4.1 ppb and 25 ppt, respectively. The 'HET' models predict the maximum ozone loss circa 2000, with the additional losses for the period 1990-2000 equal to or slightly less than those for 1980-1990. Predictions for the year 2050 depend on many competing changes in Cl_y, Br_y, NO_y (through N_2O), CH_4, and stratospheric temperatures (through CO_2 and O_3 changes), and thus the model predictions show large differences. The 'HET' models generally show increases in column ozone of 2% to 4%, reflecting, in part, a recovery of ozone depletion prior to the year 1980. By the year 2050, we may still expect some residual ozone depletion due to chlorine that is not accounted for in these models (e.g., the Antarctic ozone hole) since the tropospheric loading is still expected to exceed 2 ppb.

The peak chlorine loading in the late 1990s may vary over a range of 0.2 ppb in response to a wide variety of options for halocarbon phaseouts and HCFC substitution. A significant reduction in peak chlorine loading can be achieved with accelerated phase-out schedules of CFCs, CCl_4, and CH_3CCl_3. The time at which chlorine loading falls below 3 ppb and 2 ppb can be shifted by at most 10 years with such an acceleration of the phaseout. The integral of high chlorine levels (i.e., cumulative exposure to ozone loss) is a more sensitive measure of the difference between certain policy options: heavy substitution with HCFCs can increase this number by at most 20%; whereas, accelerated phaseouts can reduce it by more than 40%. Acceleration of halon phaseout by 3 years would reduce peak bromine loading from 23 ppt to 22 ppt in these scenarios. Stringent controls on current use of HCFC-22 or on substitution with alternative HCFCs would not significantly reduce peak chlorine loading (especially if the chlorine loading were weighted by relative ODPs).

In order to represent the different effectiveness of halocarbons in destroying ozone, we define a new quantity, the Stratospheric Halogen Loading, which is the instantaneous measure of the Cl_y and Br_y available in the stratosphere to contribute to ozone depletion (e.g., particularly in the high-latitude, lower stratosphere). The SHL is calculated from the chlorine and bromine loading by weighting individual chlorocarbons by their relative ODPs. The bromocarbons are assumed to release all of their bromine immediately in the stratosphere, and the effectiveness of Br_y relative to Cl_y in destroying ozone is expected to have a value ranging from 30 to 120. These preliminary calculations of SHL demonstrate that a large proportion (0.8 to 2.8 ppb SHL) is due to bromine, predominantly CH_3Br. But, the Br_y/Cl_y scale factor is highly uncertain: large uncertainties in the bromine chemistry kinetics, big differences in the model calculation of Br-catalyzed ozone destruction relative to Cl-catalyzed loss.

UNEP/WMO Ozone Assessment: 1991. Chapter 9.

UV Radiation Changes *(Switz1.doc Draft, 18 Oct 1991)*

R. L. McKenzie, M. Ilyas, J. E. Frederick, M. Ko, and V. Filyushkin

Scientific Summary

A major consequence of ozone depletion is an increase in solar UV radiation received at the Earth's surface. This chapter discusses advances that have been made since the previous assessment (WMO, 1989) to our understanding of UV radiation. The impacts of these changes in UV on the biosphere are not included, because they are discussed in The Effects Panel Assessment (1991). The major conclusions and recommendations are:

1. Significant improvements in the UV data base have occurred since the last assessment. Spectral measurements are becoming available, but to determine trends long-term accurate measurements of UV are required at unpolluted sites.

2. Biologically damaging UV has been observed to be more than doubled during episodes of ozone depletion in Antarctica. Smaller episodic enhancements have been measured in Australia. The observed enhancements are consistent with the results of radiative transfer calculations for clear sky conditions.

3. Erythemal Radiative Amplification factors (RAFs) of 1.25+/-0.20 have been deduced from measurements of ozone and UV at a clean air site. These are in agreement with RAFs derived from model calculations (RAF = 1.1 at 30^{o}N).

4. There is an apparent discrepancy between observed UV trends from the Robertson-Berger (RB) network and those calculated from TOMS ozone data. Cloud variability, increases in tropospheric ozone and aerosol extinctions may have masked the UV increase due to ozone depletion. In addition, the data record available for comparison is short, and the instrument calibration (which is critical) is still in question. However, at a high altitude European observatory, the observed trends appear to be consistent with ozone reductions. Further studies of the effects of cloud and aerosol on UV are required.

5. Clear-sky radiative transfer calculations using ozone fields measured by the TOMS instrument show that during the 1980s erythemally active UV has increased significantly at latitudes poleward of 30^{o}, with larger increases in the Southern Hemisphere, particularly at high latitudes.

6. Significant increases in UV effects are most likely to appear first in the Southern Hemisphere because historical ozone levels are lower there in the summer, and the Earth-Sun separation is a minimum. Further, in the Southern Hemisphere, stratospheric ozone losses are more severe, tropospheric ozone has not increased, and aerosol concentrations are lower.

7. Existing chemical models underestimate the changes in the observed ozone fields. Therefore they cannot be used to accurately predict future changes in UV fields.

Chapter 10 Ozone impacts from current subsonic and projected supersonic aircraft

Engine emissions from subsonic and supersonic aircraft include oxides of nitrogen (NOx), water vapor, unburnt hydrocarbons, carbon monoxide, carbon dioxide and sulfur dioxide. Addition of NOx to the atmosphere is expected to decrease ozone in the stratosphere and increase ozone in the troposphere. Resulting changes in ozone, water vapor and aerosol loading in the altitudes around the tropopause may have climatic impact since the sensitivity to changes in radiative forcing is maximum there.

The first step in assessing these effects is to determine quantitatively the changes in background concentrations associated with emitted gases and aerosols. Most of the emissions from the projected supersonic fleet as well as a quarter to one half of the emissions from the subsonic fleet are deposited directly into the lower stratosphere, to be redistributed by the large scale transport. Current models cannot accurately simulate the accumulation and the eventual removal from the stratosphere with much of the injection being so close to the tropopause. Model predictions in this chapter are based on simulations from two-dimensional models which assume that the emitted material is zonally mixed. The impact of flight corridor effects on the predictions has not been assessed.

The current fleet of subsonic aircraft may be sufficiently large to have increased background concentrations of NOx, ozone and the sulfate layer. Gas-phase modeling studies predict that the current subsonic aircraft (injection of 2 Tg[NO_2] /year) contributes to 5-10% of the ozone in the troposphere at around 40°N. These models also predict a decrease in the lower stratosphere of less than 1%. Projected increase in the subsonic fleet could lead to further increases of tropospheric ozone with associated change in OH and additional (although still small) reduction of ozone in the stratosphere. These estimates are subject to considerable uncertainties due to uncertainties in the magnitude and distribution of emissions, and to differences between models. The role of heterogeneous chemical processes in the troposphere needs to be assessed.

The additional impact on ozone from projected fleets of supersonic aircraft operating in the year 2015 (cruise altitudes around 15 km, 19 km and 22 km) has been examined by a model intercomparison exercise using gas-phase models. With the operation of aircraft assumed to be concentrated in the northern hemisphere, the largest decrease in local ozone is found poleward of 30°N around the cruise altitude. There is very little increase in upper tropospheric ozone because of the reduced ozone flux from the stratosphere. The calculated decrease in column abundance of ozone is larger for higher cruise altitudes and larger NO_2 emission indices for cruise altitudes below 28 km in the stratosphere. The calculated decrease in the southern hemisphere is typically a factor of 2 to 3 smaller than that in the northern hemisphere. In one of the cases (a fleet of aircraft flying Mach 3.2 between 21km and 24km with NO_2 emission index of 15 and annual fuel use of 70 Tg per year), the calculated decrease in ozone column abundance at mid-latitudes in the northern hemisphere ranges from 7% to 12%. This spread in model results increases with decreasing cruise altitude and reflects differences in transport and photochemical balance in the various models. In the Mach 2.4 case, the range of model calculated decreases in column abundance in the same region is 2-6%.

Heterogeneous reactions occurring on polar stratospheric clouds (PSC) and/or the global sulfate aerosol layer have a large impact on the predicted response to supersonic aircraft. If N_2O_5 is assumed to be converted to HNO_3 via known heterogeneous reactions on the global sulfate layer. The column changes for the Mach 2.4 case from two of the models are calculated to be small (-0.5% to +0.5%). At the same time, there is an increase in upper tropospheric ozone of about 5%. There could be additional changes in ozone if emissions from the aircraft cause enhanced formation of PSCs or increases in the sulfate aerosol loading leading to higher concentrations of ClO.

CHAPTER 11: PREDICTED ROCKET AND SHUTTLE EFFECTS ON STRATOSPHERIC OZONE

Robert S. Harwood, Charles H. Jackman, Igor L. Karol, and Lian X. Qiu

(October 18, 1991 - 12:10 p.m.)

Scientific Summary

The exhaust products of rockets contain many substances capable of destroying ozone. Although there are over a hundred rocket launches per year worldwide, studies so far have only considered the effects of the less frequent launches of the largest rockets. Most attention has focused on the potential reductions in ozone produced by chlorine compounds from solid fuel rockets. Rockets which release or are expected to release relatively large amounts of chlorine per launch into the stratosphere include NASA's Space Shuttle (68 tons) and Titan IV (32 tons) rockets, and ESA's Ariane V (63 tons).

Within a few km of the exhaust trail of these rockets, ozone may be reduced by as much as 80% at some heights for up to three hours. Since the rocket trajectory is slanted, the corresponding column ozone loss is computed to be reduced over an area of order of a few hundred square kilometers, but the depletion nowhere exceeds 10%. A satellite study of column ozone loss associated with several NASA Space Shuttle launches failed to detect any depletion. Local effects of similar magnitude may also be produced by the NOx emitted by the Soviet Energy rocket. Recovery of the ozone in the wake is computed to be rapid in all cases. All but a fraction of a percent is predicted to be restored within 24 hours.

The stratospheric chlorine input from a NASA launch rate scenario of nine Space Shuttles and six Titan IV rockets per year is computed to be less than 0.25% of the annual stratospheric chlorine source from halocarbons in the present- day atmosphere. If the annual background source from halocarbons is reduced and/or the launch rate increases, the analogous fractional contribution will become larger.

Steady-state model computations using the NASA scenario show increases in the middle to upper stratospheric chlorine amounts by a maximum of about 10 pptv (about 0.3% of a 3 ppbv background) in the northern middle and high latitudes. Independent steady-state model computations of the effect of 10 ESA Ariane V launches per year yield comparable maximum values, but at all latitudes. For both scenarios corresponding decreases in ozone are computed to be less than 0.2% locally in the region of maximum chlorine increase, leading to changes in column ozone of much less than 0.1%.

It is not yet possible to quantify with confidence the effects of particulates from the exhausts, principally of Al_2O_3 from the solid fueled rockets. However, simple steady-state estimates using the NASA scenario suggest increases of the chemically active area of stratospheric aerosols of less than 0.1%, so the long-term global impact is likely to be small.

INTRODUCTION

ENVIRONMENTAL EFFECTS OF OZONE DEPLETION

The Montreal Protocol on Substances that Deplete the Ozone Layer requires in Article 6 periodic assessments of available scientific, environmental, technical and economic information. The assessments shall be made every four years.

The latest assessments were made in 1989. For the reconsideration of the agreements in the Montreal Protocol in 1991, UNEP decided that the 1989 assessments would be updated, rather than making completely new ones. The present report is such an update of the Environmental Effects Panel Report *[UNEP, 1989]*. It focuses, therefore, on developments since 1989. Information covered in the previous report that is still up-to-date is not repeated. For this reason, the chapters of this update include the summary of the corresponding chapter in the 1989 Report.

The occasion calls for an evaluation of how research on effects of increased UV-B radiation has proceeded during the past years. We cannot conceal that progress is disappointing. Many of the "Research Needs" formulated in previous reports have to be listed again. The scientific community has followed some of the recommendations, but by no means all. Urgent problems are still waiting to be addressed.

The underlying cause has been signalled over many years by the UNEP Co-ordinating Committee on the Ozone Layer. Funding for research on the consequences of increased UV-B radiation is disproportionately low, typically less than 1 percent of what is made available for atmospheric research in relation to ozone depletion. This comment is still valid. There is improvement of funding in some countries, but this is counterbalanced by a decrease in other countries. Several research groups, having contributed important information for previous assessments, have even ceased to exist. Effects research is necessary to provide policy makers with relevant information, so that they may evaluate response strategies to future challenges. The possibility to do this in a timely fashion may well depend on the funding situation.

Increased UV-B radiation will have many effects on man, animals, plants, and materials. For several potentially important effects, our Panel could do no more than express its concern; more knowledge is needed to come to firm conclusions. The deleterious effects that we recognize are serious enough to plea for action by the nations of the world to protect the ozone layer.

J.C. van der Leun
M. Tevini

EXECUTIVE SUMMARY

SOLAR INTERACTIONS

- Significant global scale decreases in total ozone have occurred over the past ten years.
- All other factors being constant, there is no scientific doubt that decreases in total ozone will increase UV-B radiation at ground level.
- Tropospheric ozone and aerosols may have masked the consequences of stratospheric ozone depletion for UV-B in some industrialized regions.
- It is likely that in areas remote from anthropogenic emissions, the UV-B changes due to stratospheric ozone depletion would be only partially compensated by tropospheric ozone and aerosol increases.
- There are no reliable estimates of the direction or magnitude of effects of any cloud cover trends on UV-B.
- Efforts to improve local and regional air quality may bring to light the increases in UV-B associated with the depletion of stratospheric ozone.

HUMAN HEALTH

- The induction of immunosuppression by UV-B has now been demonstrated in humans, not only those of light pigmentation, but also deeply pigmented individuals. This places all of the world's populations at risk of the potential adverse impacts of UV-B on the immune system, including possible increases in the incidence or severity of infectious disease.
- An increased number of adverse ocular effects have been associated with exposure to UV. These include age-related near sightedness, deformation of the lens capsule, and nuclear cataract (a form of cataract which previous information excluded from consideration). These effects appear to be independent of pigmentation. Including nuclear cataract among the forms of cataract likely to increase with ozone depletion enlarges slightly the risk estimates. It is now predicted that, all other things being equal, a sustained 10% decrease in ozone will be associated with between 1.6 and 1.75 million additional cases of cataract per year world-wide.
- Recent information on the relationship of non-melanoma skin cancer to UV exposures confirms previous findings and has allowed refinement of the carcinogenic action spectrum. Incorporation of this new information into the risk estimation process has led to slightly lower predictions. It is now predicted that a sustained 10% decrease in ozone will be associated with a 26% increase in non-melanoma skin cancer. All other things remaining constant, this would mean an increase considerably in excess of 250,000 cases per year worldwide.

TERRESTRIAL PLANTS

- Continued research on plant responses to UV-B radiation underscores the concern for agriculture, forestry, and natural ecosystems as the ozone layer is depleted.

- Growth and photosynthesis of certain plants (e.g., seedlings of rye, maize, and sunflower) can be inhibited even under ambient levels of UV-B radiation.

- Certain environmental factors, both biotic (e.g., plant diseases and competition with other plants) and abiotic (e.g., carbon dioxide, temperature, heavy metals, and water availability), can interact with the effect of UV-B radiation in plants. This makes it difficult to make quantitative predictions.

- Although most research to date has been with plants from temperate regions, data also show that certain tropical species may be adversely affected by enhanced UV-B radiation.

AQUATIC ECOSYSTEMS

- Marine phytoplankton produces at least as much biomass as all terrestrial ecosystems combined.

- Recent results show that the aquatic ecosystem is already under UV-B stress and there is concern that an increase in UV-B radiation will cause detrimental effects.

- One consequence of losses in phytoplankton is reduced biomass production which is propagated throughout the whole food web. This may result in losses of biomass for human consumption.

- The marine phytoplankton is a major sink for atmospheric carbon dioxide. Any reduction of the populations would decrease the uptake of carbon dioxide and so augment the greenhouse effect. Also, phytoplankton production of DMS (dimethylsulphate), which acts as a precursor of cloud nucleation, would be reduced, hence potentially affecting global climate.

- A UV-B induced decrease in microorganisms fixing atmospheric nitrogen would require significant substitution by artificial fertilizers, e.g., in rice production.

TROPOSPHERIC AIR QUALITY

- Chemical reactivity in the troposphere is expected to increase in response to increases in UV-B.

- Tropospheric ozone concentrations could rise in moderate to heavily polluted areas, but should decrease in unpolluted regions (with low oxides of nitrogen levels), as recently confirmed by measurements in the Antarctic.

- Other potentially harmful substances (hydrogen peroxide, acids, and aerosols) are expected to increase in all regions of the troposphere due to the enhanced chemical reactivity.

- These changes could exacerbate problems of human health and welfare, increase damage to the biosphere, and might make current air quality goals more difficult and expensive to attain.

MATERIALS DAMAGE

- UV-B radiation is particularly effective in light-induced degradation of wood and plastic products, leading to discoloration, and loss of strength. Increased UV-B content in sunlight will cause more rapid degradation, resulting in increased costs of using higher levels of conventional light stabilizers, possible design of new stabilizers, and faster replacement of the affected products.

- Available research data are inadequate to reliably estimate the damage from higher UV-B levels to materials. Very limited relevant data are available for important classes of materials such as wood, plastic coatings, plastics used outdoors, and rubber. Data pertaining to performance of plastics in near-equator regions of the world, with the harshest exposure environments, are particularly needed.

- Some on-going work relating to exposure of plastics under desert conditions is likely to contribute some of the needed data within the next few years. This may lead to improved assessment of damage to plastics resulting from partial ozone depletion, at that time.

OZONE & GREENHOUSE: RECENT FINDINGS

SUMMARY FOR: SENATE STAFF

RUSSELL BLDG., 24 OCT 91
WASHINGTON, DC

DAN ALBRITTON (NOAA) & BOB WATSON (NASA)

- BASIS: "SCIENTIFIC ASSESSMENT OF OZONE DEPLETION: 1991"
  - PREPARED FOR U.N. MONTREAL PROTOCOL UPDATE.
  - WRITTEN BY ~40 SCIENTISTS WORLDWIDE.
  - MAIL PEER REVIEWED BY ~50.
  - WORKSHOP REVIEW/COMPLETION 14-19 OCT, SWITZERLAND. ~80 SCIENTISTS, 25 COUNTRIES.
  - TO BE PRINTED ~ 15 NOV - 1 DEC
  - PRESENTED TO THE UN ENVIR. PROG. ~ FEB 92.
  - MEETING OF PROTOCOL SIGNATORIES ~ JUL 92.

- TODAY'S SUMMARY: TWO MAIN TOPICS...

① OZONE LAYER DEPLETION

WHAT IS NEW IN THIS "OLD" STORY?

② OZONE DEPLETION & GREENHOUSE EFFECT

HOW ARE THESE TWO INTERRELATED?

(FOR BOTH: THE RELATION TO POLICY)

① STRATOSPHERIC OZONE DEPLETION

- **WHAT WE ALREADY KNEW:**

POLAR REGIONS:
- THE ANTARCTIC OZONE HOLE IS MAN-MADE ☑
  - CFCs, HALONS, AND OTHER EMISSIONS
  - THEIR EFFECT IS ENHANCED THERE BECAUSE OF ICE PARTICLES
  - THE HOLE WILL BE THERE A LONG TIME ~75 MIN
- NO "HOLE" IN ARCTIC, BUT LONG, COLD WINTERS COULD YIELD SIGNIFICANT OZONE LOSS.

But do have depletion

GLOBALLY:
- 1989 UNEP/WMO REPORT:
  - "DOBSON" NETWORK – DOWNWARD TRENDS MID-TO-HIGH LATS NH
    - WORSE IN WINTER ?
    - LARGER THAN PREDICTED WITH GAS-PHASE MODELS
- 1991 SATELLITE STUDY (STOLARSKI - NASA)
  - "TOMS" DATA – BOTH HEMISPHERES
    - FASTER LOSS IN 1980s THAN IN 1970s

- **WHAT IS NEW?** ("1991 UNEP/WMO REPORT")

POLAR REGIONS:

one of the strongest observations

- THE "CAUSE&EFFECT" PICTURE IN ANTARCTICA IS NOW EVEN STRONGER (LAB, FIELD, THEORY)
- THE ODD/EVEN-YEAR FLUXUATION IN THE HOLE'S SEVERITY HAS NOT OCCURRED THE PAST 3 YEARS:

STRONG →	...		1987		1989	1990	1991
WEAK →		1986		1988			

(REASON? NOT CLEAR – MAYBE CHEMISTRY HAS SWAMPED THE DYNAMICAL FLUXUATIONS NOW?)

(WHAT'S NEW? CON'T)

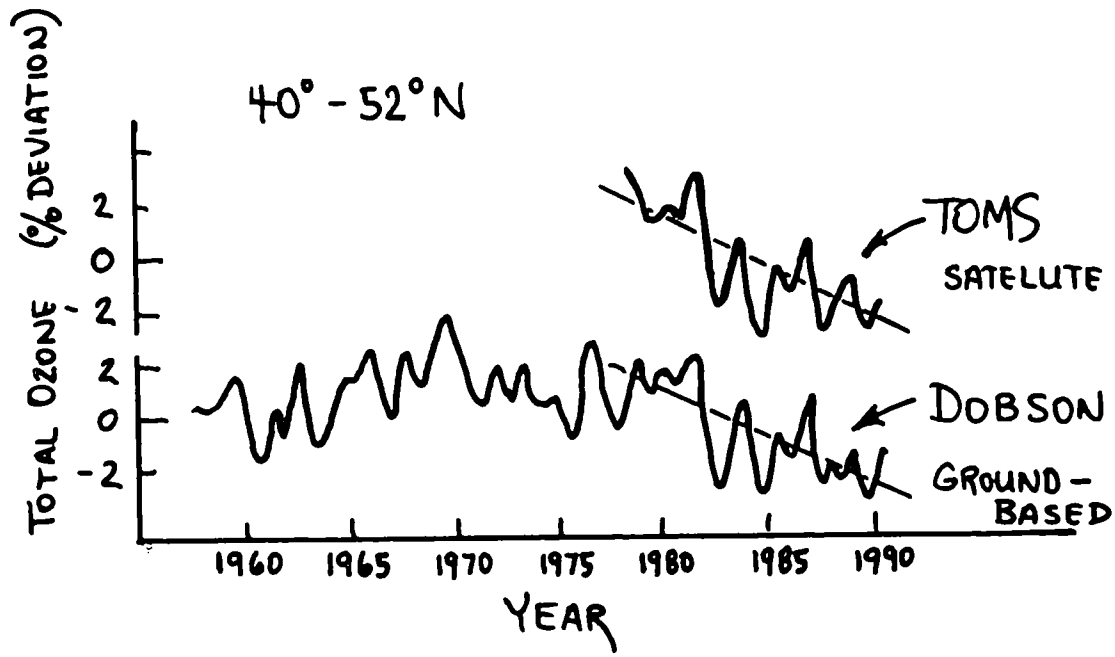
GLOBAL OZONE:

- THE DOWNWARD TRENDS IN BOTH HEMISPHERES ARE NOW IN FALL, SPRING, & SUMMER.
  - "DOBSON" DATA ANALYSIS: (BISHOP, 1991)
  - EXAMPLE: BETWEEN 26°N - 64°N -

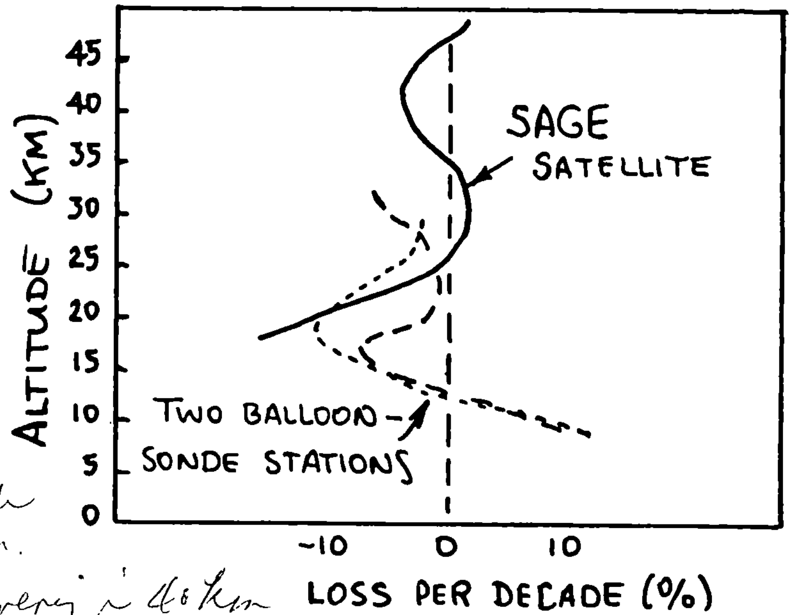
old data not wrong - uncertainty larger

	1979-1991	1970-1991	
	-3.3±1.2	-1.3±0.4	% PER DECADE

- SEEN IN 2 INDEPENDENT DATA SETS. (CONFIDENCE BUILDING!)



- THE LOSSES ARE CLEARLY IN THE LOWER STRATOSPHERE.



} LOSS REGION-
12-25 KM

8-10% loss per decade in vicinity of 18 km.
before thought was happening in 40 km

KEY POINT!

- CAUSE(S)?
  - NOT COMPLETELY CLEAR YET
  - BUT WEIGHT OF EVIDENCE INDICATES...

> ACCELERATED CHLORINE/OZONE CHEMISTRY DUE TO SULFATE AEROSOL LAYER (EVER-PRESENT)
>
> ITS AT THIS ALTITUDE
>
> LAB DATA SHOW SPEEDING-UP REACTIONS
>
> MODELS WITH THIS CHEMISTRY SIMULATE MUCH (BUT NOT ALL) OF THE OBSERVATIONS

This is the layer of the strat. where [illegible] layer [illegible] and [illegible] layer

ice layer at poles at roughly the same altitude

> NO NON-CHLORINE EXPLANATIONS ARE SUPPORTED BY OBSERVATIONS.

midlats. are the denser parts of the layer

nitrogen oxides readily take ozone out → [illegible] now [illegible] go ahead w/ aerospace plane.

- IMPLICATIONS OF OZONE LOSSES

  - WITHOUT MONTREAL PROTOCOL (1987, 1990) CHLORINE WOULD RISE INDEFINITELY. LARGE OZONE LOSSES!

  - CURRENT SITUATION:

    - CHLORINE MAY PEAK AT ~ 4.1 PPBV AT ~2000 OR LATER. (3.4 PPBV NOW)

    - ADDITIONAL OZONE LOSSES - 1990's?

      AT LEAST THOSE OF 1980's — 3-4% MORE (ASSUMING NO SURPRISES!)

      cumulative -- will wind up w/ ~8%

  ⇒ FOCUS OF POLICY DEBATE:

  1. HOW HIGH SHOULD WE LET IT GO?
  2. HOW LONG SHOULD PEAK LEVEL BE ALLOWED?

  SPECIFICS -

  - SPEED UP PHASE OUTS: CFCs, HALONS, ...?
  - SELECTIVE USE OF SUBSTITUTES?
  - METHYL BROMINE SOURCE?

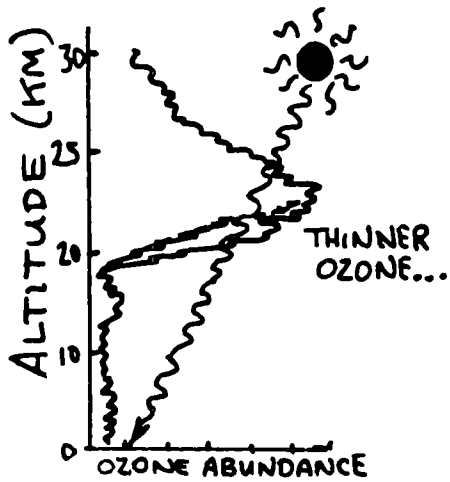
  THE WMO/UNEP 1991 REPORT LAYS OUT OPTION/CHLORINE SCENARIOS

Q: 18 km above enough to make a differ

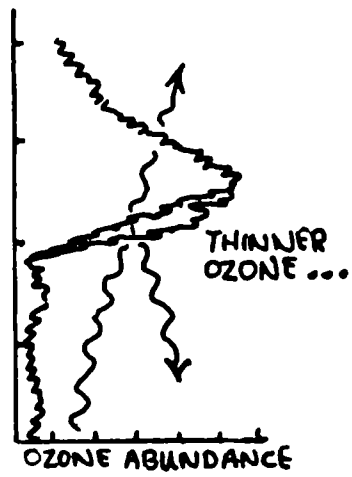
② OZONE LOSS & GREENHOUSE FORCING

(A FIRST LOOK AT THE RADIATIVE EFFECTS OF LOWER-STRATOSPHERIC OZONE LOSSES.)

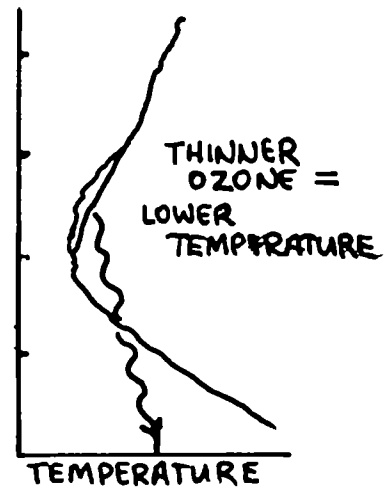
- **MECHANISMS:** THREE COMPONENTS...



MORE VISIBLE/UV RADIATION GETS THRU
+ FORCING



LESS SURFACE IR ESCAPES TO SPACE
− FORCING



LESS IR RADIATION TO SURFACE
− FORCING

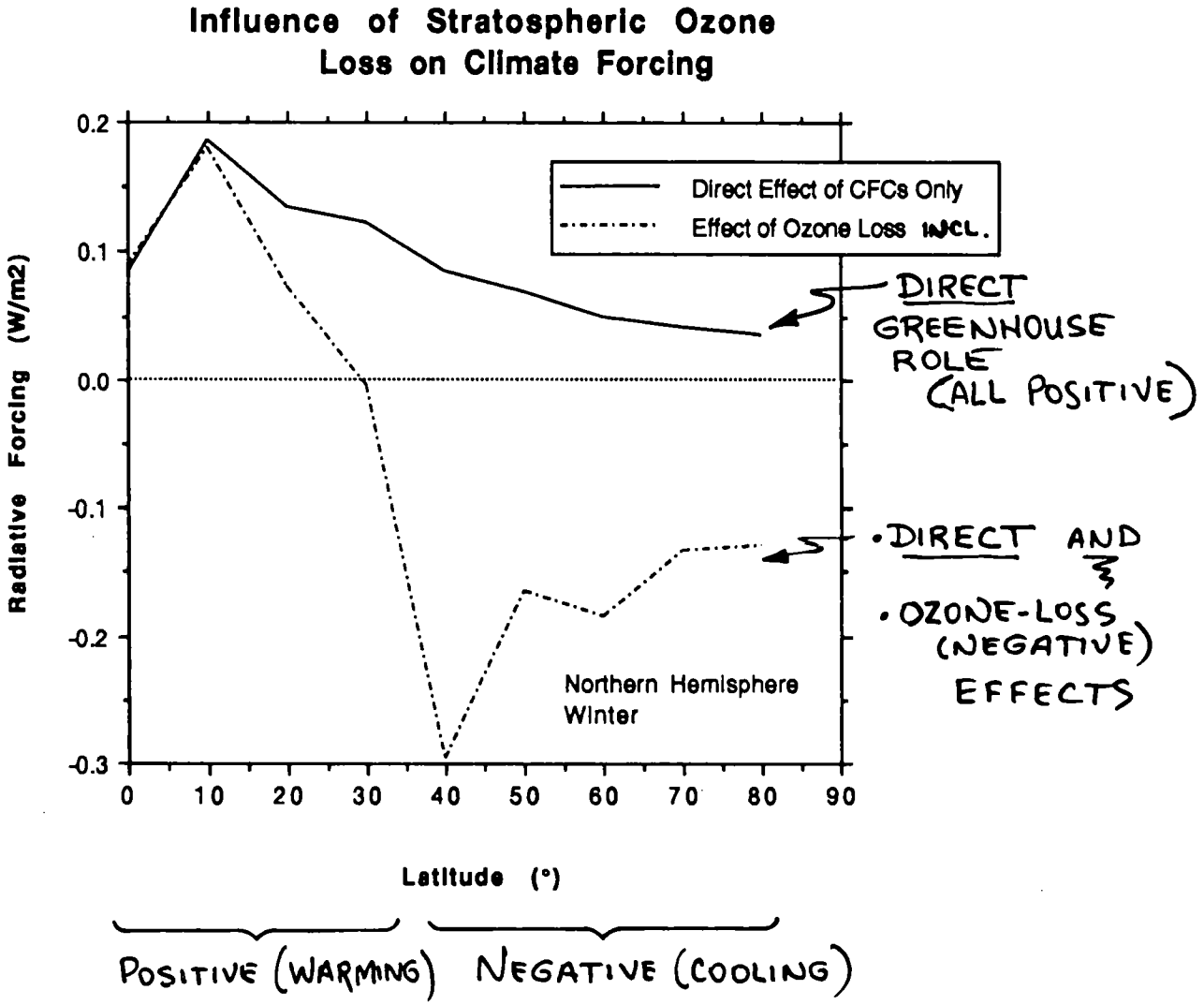
DOMINANT TERM!

NET EFFECT: − RADIATIVE FORCING (I.E., A TENDENCY TOWARD COOLING)

A FEW POINTS:

- THE EFFECTS "TRACKS" LOWER-STRATOSPHERIC OZONE LOSS
  - SEASONAL VARIATION (LARGER IN WINTER)
  - LATITUDINAL DEPENDENCE (LARGER AT HI LATS)

PRELIMINARY CALCULATIONS:



THAT IS: NET RADIATIVE EFFECT OF CFCs MAY BE ~0!

BOTH: AS THEY WERE ADDED TO THE ATMOSPHERE (1945 - NOW)

AS THEY ARE REMOVED (NOW - 2100)

• PERSPECTIVE:

- CALCULATIONS DONE WITH SEVERAL RADIATIVE MODELS
  E.G., NOAA, STATE UNIV. NEW YORK, UK-READING UNIV,
  GENERAL AGREEMENT ON OVERALL PATTERNS

- IMPLIED TEMPERATURE COOLING OBSERVED
  ABOUT −0.3°C PER DECADE (−2° PREDICTED)
  MORE IN ANTARCTICA

- HENCE, WHILE MUCH MORE NEEDS TO BE DONE, THE RESULTS ARE LIKELY ROBUST.

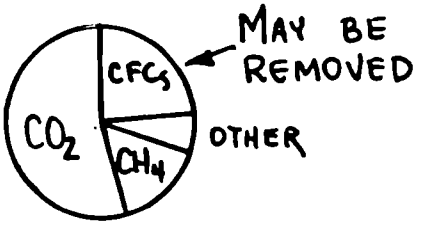
  THERMAL/DYNAMICS COUPLING
  CLOUDINESS
  } INITIAL RESULTS, BUT STILL COMPLICATED

• IMPLICATIONS TO POLICY FORMULATION:

- THE CFCs MAY WELL BE CLOSE TO "GREENHOUSE NEUTRAL".

- THE PICTURE THAT CFC ELIMINATION WILL REDUCE RADIATIVE FORCING (E.G., OFFSET THAT OF CO_2) HAS CHANGED.

- THE GREENHOUSE LIST HAS CHANGED:



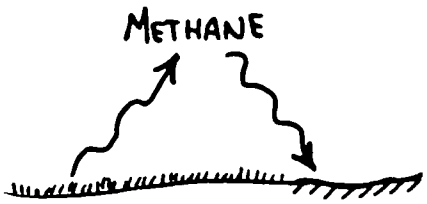
- THE RADIATIVE FORCING MAYBE HAS BEEN SLIGHTLY OVERESTIMATED (~20%) (GOOD NEWS!!)

APPENDIX:

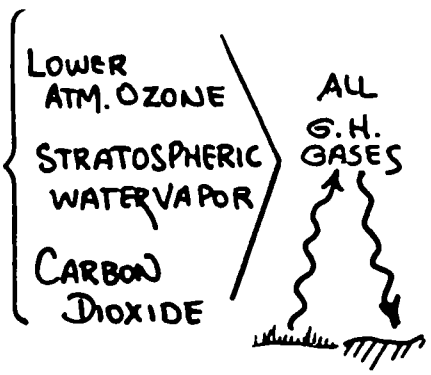
GLOBAL WARMING POTENTIALS: NEW RESULTS

- **BACKGROUND:**
  - TRACE GASES CONTRIBUTE TO GREENHOUSE FORCING IN 2 WAYS...

DIRECT EFFECT



INDIRECT EFFECT



  - GLOBAL WARMING POTENTIALS (GWPs) ARE USED TO INTERCOMPARE GASES

GWP = DIRECT + INDIRECT

CARBON DIOXIDE	1	(REFERENCE)		IPCC, SCIENCE ASSESSMENT, 1990
METHANE	21	6	15	
NITROGEN OXIDES	40	–	40*	
CFC-11	3500	3500	–*	

* COMMENT BELOW

Policy relevance of not knowing nitrogen oxides & CFCs → doubt on comprehension

- **RESULTS OF RECENT STUDIES:**

  - **DIRECT EFFECTS** OF WELL-MIXED GASES : ☑

    EXAMPLES : CARBON DIOXIDE, CFCs, NITROUS OXIDE, ...

  - **INDIRECT EFFECTS**: HARDER THAN ORIGINALLY REALIZED!

    - DIFFERENT RESULTS AMONG VARIOUS MODELS
      E.G., METHANE – 50%
      NITROGEN OXIDES – FACTORS OF 3
    - IPCC USED ONLY 1 MODEL (DIDN'T SEE THIS)
    - SCRUTINY SHOWS MANY PROCESSES ARE UNCERTAIN
    - PARTICULARLY FOR "POLLUTION" GASES
      E.G., NITROGEN OXIDES: INFLUENCE + LOWER ATM. OZONE / – METHANE
      NET: TOO CLOSE TO CALL

- **IMPLICATIONS FOR POLICY DECISIONS:**

  - GWPs WILL BE HARDER TO FORMULATE THAN THOUGHT –
  - DIRECT EFFECTS OF LONG LIVED GASES - OK
  - BETTER METHANE GWP ~ 6 MONTHS
  - REST – WILL REQUIRE BETTER MODELS
  - A COMPREHENSIVE APPROACH TO GREENHOUSE GASES WILL BE HARDER TO APPLY.

short-lived & hydrocarbons – IPCC ignores