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AN ENVIRONMENTAL ASSESSMENT OF OZONE LAYER DEPLETION AND ITS IMPACT

paper prepared by the

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OZONE OBSERVATIONS

1. The ultimate test of the ozone depletion theory depends on the detection of long term changes in global total as well as vertical, ozone distribution, which in turn requires a continuous and comprehensive flow of reliable data from the ozone observing system. Ground-based measurements form an important element of the system, both on their own account and by providing the ground truth data for satellite-based systems, which can provide more comprehensive information on both total and vertical ozone distribution. However, good ozone measurements are difficult to make, and their interpretation subject to many uncertainties (e.g. long-term instrumental drift) and high natural variability (e.g synoptic, seasonal, solar, etc.).

2. Total ozone: During the past six years about fifty Dobson ozone-spectrophotometers were upgraded and/or intercompared with either the world primary standard instrument located at NOAA-Boulder, Colorado, USA, or a regional (secondary) standard instrument. Most of the Dobson ozone data reported to the World Ozone Data Center (WODC) - Toronto, are obtained from these instruments. The importance of these intercomparisons is reflected in the calibration errors discovered which have been more than 7 percent in a few instances. Although shown by only a few instruments, these differences indicate the existence of stations generating data at times with large errors. The precision of a well kept Dobson instrument network is estimated to be $\pm$ 1.5% for calculations of global annual means. However, the accuracy of the network could be considerably worse due to the uncertainty of the absorption coefficients. Drifting of instrument readings was also demonstrated, and frequent (once in three to four years) intercomparisons are therefore considered essential.

3. There is still room for improvement in the data obtained from the ground-based total ozone network - both in quantity and quality. There is spatially uneven distribution of the stations - about two-thirds of the total number of stations are located between 30°N and 60°N. More even distribution, frequent instrumental checks and increased regularity of observations could have a positive effect on the quality of the data.

4. Approximately one third of the existing ground-based stations do not report regularly to the World Ozone Data Center - Toronto, and therefore could not be used in trend analyses. Of the number regularly

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reporting, a significant fraction (~ 20%) provides data derived from lower quality filter instruments. The International Ozone Commission has concluded that the performance characteristics of another instrument (the Brewer spectrophotometer) meet all observational requirements, will not distort the homogeneity of the network, and therefore has recommended its inclusion in the ozone measuring network, supplementing or possibly replacing some of the Dobson instruments.

5. Vertical Ozone Distribution: The predicted percentage depletion of the ozone concentration at upper stratospheric levels due to CFC releases is calculated to be several times greater than the corresponding predicted depletion of the total ozone amount. Thus data from this level should provide the most sensitive information for ozone perturbations. This strongly supports the need of vertical ozone distribution data.

6. So far, ground-based Umkehr measurements represent the largest set of data for vertical ozone distribution. This set is especially useful for analysis of the 25 to 50 km region in the atmosphere. However, only about a dozen stations make them regularly. Recently a new "short Umkehr" multi-wavelength method has been developed and should be widely encouraged. Direct measurements by balloon borne sondes are needed for more detailed analyses of vertical ozone distribution, circulation studies etc. The network of ozone-sondes are known to be inadequate as less than a dozen stations make weekly balloon ozone soundings and only a few have continuous records longer than ten years. International intercomparisons of various types of operational ozone-sondes have been conducted twice, in 1970 and 1978/80. Other comparisons are planned for 1982. Efforts should be directed toward the continuation and improving of balloon ozone-sondes in parallel with the increase of indirect measurements of vertical ozone distribution by, for example, the Umkehr method.

7. Satellite Measurements: The past ten years have seen the development of several satellite-borne instruments for measurements of both the total column and vertical distribution of ozone using a variety of experimental techniques. The instruments that have, or are, currently being used to measure:

(i) total column ozone - are based on the techniques of Solar Backscattered Ultra-Violet (BUV, SBUV/TOMS) and Infra-Red radiance in the 9.6 um band (IRIS, MFR, HIRS-2). The data which have been processed and validated are proving to be most valuable. There is a systematic difference between near simultaneous BUV and Dobson total ozone observations, the Dobsons being at the average about 7 percent higher.

(ii) vertical ozone distribution - are based on the same basic techniques as for total column ozone, i.e. Solar Backscattered Ultra-Violet (BUV, SBUV) and Infra-Red radiance in the 9.6 µm band (LRIR, LIMS). In addition, the technique of solar occultation in the visible region has been used (SAGE). The BUV data and part of the SBUV are now available; the data from other satellite instruments are now being validated and processed.

8. In future years satellite systems will play an increasing role in the monitoring of ozone. Supported by Umkehr measurements, they provide the best means for early detection of anthropogenic influences on the ozone layer in the upper stratosphere. Present satellite systems should continue to be supported in parallel with efforts to improve their accuracy and reliability.

9. Rocket-borne ozone-sondes: Rocket-borne measurements are necessary mainly for satellite instrument calibration. About sixty recent inter-comparative flights should enable an assessment to be made of data derived from previous rocket soundings and is expected to improve our knowledge of the upper stratospheric ozone distribution.

10. Global Ozone Observing System (GOOS): Careful assessment of the performance characteristics of the various ozone observing systems concluded that a continuous flow of reliable, total and vertical ozone data forming a coherent set could be achieved by integrating the ozone observing system using the satellite-borne observing systems and a set of well maintained ground-based stations. In order to achieve full integration there is a strong need for intercomparisons of routine by used ozone-sondes with different research type sondes in order to clear up certain remaining discrepancies in the 30-35 km region.

OZONE DATA ANALYSIS

11. The relatively large natural variability of atmospheric ozone makes detection of trends difficult. The ground-based Dobson network indicates that between 1965 and 1980 several periods of increases and decreases have

occurred with ranges of one to several percent changes, each lasting several years. There exist indications of a possible solar cycle variation which is yet difficult to assert with any statistical certainty. There is no evidence of an overall change of greater than 2% in total ozone between 1958 and 1980. More refined statistical analyses of data from 36 selected Dobson stations confirms this finding and shows no evidence of a statistically significant trend in the period 1970 to 1979.

12. Total ozone measurements from the backscattered ultraviolet (BUV) Nimbus-4 satellite so far analysed for limited period, show a time-varying discrepancy with data from the Dobson network. It is presumed that there has been a drift in the satellite measurements. Without correcting this apparent drift, the satellite indicates about a 1% greater ozone decrease between 1970 and 1974 than does the Dobson network. The attempt to correct for the drift results in essentially no change in satellite-derived ozone amount between 1970 and 1974, in comparison with the Dobson decrease of nearly 2%. In future, because of the excellent spatial coverage of a satellite system, proper intercalibration with the Dobson network should permit a considerable improvement in global total ozone values. It is estimated that the mean monthly global total ozone value so obtained should be in error by no more than 1 percent.

13. Any potential influence on ozone amount caused by chlorocarbons should be most apparent near 40 km, at a height where photochemistry dominates transport effects. It is as yet uncertain to what extent the Umkehr derived 10% increase in the 32-48 km layer in North temperate latitudes between 196‚ and 1970 is real (possibly due to the tendency for a greater ozone amount at sunspot maximum) and to what extent it is artificial, caused by the effect on the Umkehr method, of aerosols injected into the stratosphere at the time of the eruption of Mt Agung (1963) and their subsequent decrease. In the same layer (32-48 km) there was an appreciable (about 4%) decrease indicated immediately following the Mt. Fuego eruption in 1974. The ozone concentration in this layer by 1979/80 had slowly reached the same value as in 1973/74. A study of data for 32-48 km layer from 12 Umkehr stations in the northern hemisphere, over the period 1970-79, indicates that no statistically significant change could be detected. Satellite data from same altitude layer when published should provide additional information which need to be interpreted carefully.

14. There is a discrepancy between Umkehr-derived and ozone-sonde-derived ozone trends in the 16-32 km layer of North temperate latitudes, the Umkehr measurements indicating essentially no change in ozone amount between 1970 and 1979, the ozone-sondes an ozone decrease of a few percent Thus, in this layer we cannot be sure of the actual ozone variation

15. In the 2-8 km (tropospheric) layer the ozone-sondes indicate an approximate 20% increase in ozone between 1967 and 1980 in North temperate latitudes. A similar increase in North polar latitudes makes in unlikely that this increase is due to local sources of urban photochemical pollution in the troposphere Thus, the ozone-sondes data suggest that the near invariance in total ozone in the last decade has been associated with a partial balance between the possible stratospheric ozone decrease and indicated tropospheric ozone increase.

OZONE TREND DETECTION

16. With reference to the question: How well can we establish the effects of man-induced activity on any change in total ozone? It is recognized that, even though a reasonably accurate determination of the global total ozone can be obtained, it does not mean that anthropogenic effects can be easily detected The key issue is the relatively large natural variability in total ozone. With a data record of only about twenty years it is not possible to specify with confidence this natural variability. Consequently, anthropogenic influences, with the possibility of additional simultaneous positive and negative effects of different origin, cannot easily be delineated even by sophisticated statistical techniques at this time.

17. It was noted that the estimate of total ozone change determined recently in three studies was a statistically nonsignificant increase of 1 percent for the period 1970-79 with an uncertainty averaging $\pm\sim$1.5 percent. The effor limits (95% confidence limits) reflect the natural, spatial and instrumental uncertainties that are revealed in the analysed data.

[illegible]. Such recent developments in statistical methods show that at present, a trend attributable to combined anthropogenic sources in the total ozone of 2% change since 1970, is the smallest that could be detected by the Dobson monitoring network. However, on meteorological considerations, taking into account possible influences and effects unrevealed by the statistical analyses, the threshold may be as high as 4 percent. As the data record becomes longer, this statistical analysis for the detection of trends may improve its precision

SOURCES AND SINKS OF CFC'S

18. World production of CFCs 11 and 12 combined as estimated by the Chemical Manufacturers Association (CMA) has fallen by a total of 18 percent between 1974 and 1980 from 851 kt p.a. to 696 kt p.a. (thousand metric tonnes). Most of the decrease occurred in the years 1974 to 1977; only 1% decrease took place in the past year, please refer to data supplied by CMA for full details. These estimates are based on data supplied to the CMA by reporting companies with an estimated accuracy of 5% together with an uncertain 8% contribution from countries not reporting to the CMA. Data from non-reporting countries is needed in order to improve the accuracy of estimates of global production. The corresponding estimated releases of these CFCs have fallen from 741 kt to 591 Kt between 1974 and 1980.

19. From the data of the reporting companies only, there has been a reduction in the annual combined use for aerosols and open cell foam (giving immediate atmospheric release) from 610 Kt to 350 Kt over the period 1974 to 1980 but an increase in the annual amount used in refrigeration and closed cell foams (delayed release) from 203 Kt to 290 Kt over the same period. It is recognized that eventually the reduction of CFC use in aerosols could be offset by growth in non-aerosol uses This indicates the important of monitoring all uses of CFCs 11 and 12.

20. Present model estimates of ozone depletion due to CFCs 11 and 12 allow for their destruction only in the stratosphere. The presence of a loss mechanism in the troposphere would cause a reduction in their overall lifetimes and a commensurate reduction in the resulting estimate of ozone depletion at steady state assuming continued release of CFCs at constant rates.

21. Atmospheric measurements of CFC-11 and CFC-12 have revealed a steady increase throughout the troposphere over the past decade. In principle, such measurements when taken with atmospheric release data, can be used to derive atmospheric lifetimes for CFC-11 and CFC-12 and hence determine whether there are significant tropospheric sinks. A network of five measurement stations has been set up in locations remote from significant CFC sources to acquire long-term data for CFC-11 and CFC-12 (together with carbon tetrachloride, methylchloroform, CFC-113 and nitrous oxide) using regular calibration with the specific objective of establishing atmospheric lifetimes. This objective should be achieved

in a few year , but there will be a continuing need to maintain a global monitoring network of comparable quality for CFCs 11 and 12, together with other chlorocarbons for a much longer period to provide an independent check on release data. In addition, efforts seeking direct evidence for the existence of specific tropospheric sinks are continuing. At this time the available information is not sufficient to be properly evaluated.

22. No organisation currently collects global production data for halocarbons other than CFC 11 and 12, which may affect the ozone layer. Less extensive atmospheric data are available for these compounds of which the most significant are methyl chloroform (CH_3CCl_3), carbon tetrachloride (CCl_4) and CFC-113 ($CCl_2F\ CClF_2$), but there are a number of others which need to be considered in a full treatment. Based on approximate estimates of current production these substances would cause in the steady state an additional ozone depletion of about a third of that due to CFC-11 and CFC-12. However, the production of methyl chloroform and some others has grown substantially in the recent past, and there has been a corresponding increase in atmospheric concentrations though these data are rather fragmentary. If this growth were to continue while the production of CFC-11 and CFC-12 remains constant or declines, then these other compounds could assume an importance equal to that of CFC-11 and CFC-12 at some time in the future. Thus there is a clear need to acquire relevant global release data and to extend corresponding atmospheric measurements.

ATMOSPHERIC PHOTOCHEMISTRY

23. During the last few years considerable progress has been made in the laboratory measurement of rate coefficients, cross-sections, and primary quantum yields for use in atmospheric modelling. However, a number of problems remain, ranging from small differences in results for a given parameter obtained by different laboratories, to the possibility that major processes have not been incorporated into the photochemical model. The following discussion will emphasize the uncertainty in those processes which are not well defined, and for which the ozone perturbation calculations are sensitive, rather than discussing the large majority of processes for which the present data base is thought to be well established. Increased emphasis is currently being placed on understanding reaction mechanisms over the full range of atmospheric temperatures and pressures since the partial pressures of other gases such as water vapour,

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or oxygen, may occasionally affect reacion rates, and in addition, certain reactions may proceed via multiple reaction pathways

24. The chemistry of the global troposphere is complex with both homogeneous and heterogeneous (for example rain-out) processes playing important roles. Significant progress has been made in understanding the coupling between the carbon/nitrogen/hydrogen/oxygen systems, and the details of the hydrocarbon oxidation mechanisms which play a vital role in controlling tropospheric hydroxyl radical concentrations. This is an important development insofar as the hydroxyl radical plays a central role in photochemically controlling ozone in the troposphere and controlling the tropospheric concentrations of gases such as CH_3Cl and CH_3CCl_3. In the context of stratospheric chlorine photochemistry (i.e. a coupled oxygen/nitrogen/hydrogen/chlorine system) it should be stressed that the basic formulation remains unchanged from that originally forwarded by Rowland and Molina in 1974, namely that there are no identified catalytic cycles involving chlorinated species which are thought to result in the production of odd oxygen. The numerous changes that have been made in estimates of certain rate coefficients have predominantly involved temporary reservoirs such as COCl, HO_2NO_2, HNO_3, and $ClONO_2$ This has modified our understanding of the lower stratosphere, but not our basic perception of the role of ClO_x in the photochemically-controlled region above 30 km where temporary reservoirs such as HOCl and $ClONO_2$ play a far less significant role. In turn each chemical family is discussed below, although it is recognized that there is strong coupling between each of them.

25. <u>Odd-Oxygen Reactions (O_x)</u>: The key photochemical processes involving O_x species only, are now considered to be well understood. Minor uncertainties still exist in certain processes but these uncertainties do not cause significant problems for stratospheric modelling

26. <u>Odd-Hydrogen Reactions (HO_x)</u>: The rate coefficients for reactions which control the abundance and partitioning between the odd-hydrogen radicals (OH and HO_2) are required with high accuracy due to the central role that the hydroxyl radical plays in controlling the catalytic efficiencies of both NO_x and ClO_x. Unfortunately, some of the largest uncertainties and most significant recent changes in rate coefficients fall within this category of reactions. Most simple OH reactions were, until quite recently, thought to be well established, however, recent work on $OH+H_2O_2$ and $OH+HNO_3$ has shown this belief to be incorrect. As

was suggested in the last report the key reactions, $OH + HNO_3$, $OH + HO_2NO_2$, $OH + HO_2$ have been studied during the past year and this has led to a new balance among chemical catalytic cycles in the lower stratosphere. Understanding the reactivity of the HO_2 radical still remains one of the major problem areas in atmospheric photochemistry. However, while it is essential to understand the effect of H_2O vapour or HO_2 reactivity, it is important to recognize that such effects will be significantly more important for tropospheric and lower stratopsheric than for upper stratospheric photochemistry. The question of pressure and temperature dependence of OH and HO_2 reactions continues to be important and requires extensive study especially in view of the unusual pressure dependence observed in certain reactions ($OH + CO$, $HO_2 + HO_2$), and the unusual temperature dependence observed in others ($HO_2 + HO_2$, $HO_2 + ClO$, $OH + HNO_3$).

27. <u>Odd-Nitrogen Reactions (NO_x)</u>: In general, the kinetic data base for NO_x reactions is relatively good. The major problem areas have already been outlined in the previous section (e.g. processes involving HNO_3 and HO_2NO_2). The decrease in HO_x concentrations in the lower stratosphere has significantly enhanced the role of odd nitrogen in this region. Additional studies of processes involving NO_3, N_2O_5 are required but are unlikely to have a major impact on modelling results.

28. <u>Odd-Chlorine Reactions (ClO_x)</u>: The kinetic data base for ClO_x reactions has improved significantly in the last few years, but there are still several areas of concern. The problem of which isomers of $ClNO_3$ are formed in the $ClO + NO_2 + M$ reactions, and what the dissociation products of these isomers could be, has still not been resolved. Recent changes in the relative importance of ClO_x in the lower stratosphere have reduced the model-predicted influences of CFCs on ozone, particularly in the lower stratosphere. Last year's results on the temperature dependence for HOCl formation and the absorption cross section of HOCL coupled to the recent decrease in estimated HO_x concentrations in the lower stratosphere has considerably reduced the importance of HOCl.

29. <u>Odd-Bromine Reactions (BrO_x)</u>: The lessened importance of ClO_x in the lower stratosphere has for all practical purposes eliminated any potential impact of BrO_x on ozone chemistry at current stratospheric concentrations.

CURRENT STATUS OF MODEL PREDICTIONS

30. Most predictions of stratospheric ozone depletion from man-made causes continue to rely on one-dimensional (1-D) models. The principal

focus remains with the impact of continued release of CFC-11 and CFC-12 although there are many other factors which may influence the stratospheric ozone amount over a similar time scale. Ignoring all other potential changes, current predictions of the impact of continued release of CFC-11 and CFC-12 at the 1977 rate range from about 5 to 10 percent ozone depletion in steady state* compared with the value of 10 percent given at the UNEP Co-ordinating Committee on the Ozone Layer held in November 1980. This downward revision has been caused mostly by adjustments to the rate co-efficients of the above mentioned HO_x reactions. This range merely reflects the uncertainty in our quantitative understanding of HO_x chemistry and transport parameterisations in the lower stratosphere. Other uncertainties which are not included directly in the above range are discussed in paragraphs 45-50 below. The estimate of the present total column ozone depletion due to CFC-11 and CFC-12 alone, has been similarly reduced and is less than 1 percent, which is below the present detection limit.

31. Two-dimensional model studies show that variations of the predicted ozone depletion with latitude and season are to be anticipated. The maximum reduction occurs in the late winter/early spring with a minimum in late summer/early autumn. There is a greater reduction at high latitudes than in the equatorial regions, with slightly more overall reduction in the northern hemisphere than in the southern hemisphere. The differences between mean reductions at low latitudes and high latitudes are qualitatively the same in all 2-D models although not identical quantitatively. The research community is still in the process of developing a full understanding of 2-D models. These latitudinal and seasonal variations have implications for changes in the intensity of UV-B radiation at the earth's surface as compared to the global average results of 1-D models. The 2-D model predicted global averaged changes are in good agreement with the corresponding estimates from 1-D models

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*Although "steady state" in the current sense is a mathematically well-defined situation, its physical meaning is simply the condition in the future when all relevant variations in time of all the parameters of interest have been reduced to a very low level. The length of time required in reaching such a condition differs greatly from scenario to scenario (see para 46).

32. The predicted ozone reduction shows significant variations with altitude with the greatest percentage depletion of about 35% predicted to occur locally at about 40 km in steady state The present-day estimated local ozone reduction around 40 km is expected to be around 4%. The recent changes in the HO_x chemistry have less effect on the percentage ozone reduction prediction in this region than in the lower stratosphere where the bulk of the ozone column resides.

33. Whether the models realistically forecast what is likely to happen in the stratosphere depends on the correctness and completeness of their input data and their coverage of the simultaneous effects of other atmospheric pollutants It is not realistic to consider global ozone reductions in terms of releases of CFC-11 and CFC-12 alone. Many other factors may increase or decrease the global amount, and it is this combined effect which will determine what will actually happen to the ozone layer. A full study must take them all into account since they may interact together in a non-linear manner typical of a highly-coupled system. In addition to the natural perturbing effects such as lightning, volcanic eruptions cosmic rays, solar proton events, global circulation changes and the variability of solar radiation, consideration should be given to:

(i) Other man-made chlorine-contained compound such as methyl chloroform, carbon tetrachloride and other chlorofluorocarbons, (CFC-113, CFC-114, CFC-115 and CFC-22). The potential for future growth in their atmospheric releases is more difficult to assess but estimates indicated that if releases continue at present levels then they could increase the steady state ozone depletion from CFC 11 and 12 alone by about one third. Most of this enhancement is derived from the release of CCl_4, CFC 113 and methyl chloroform, with minor contributions from CFCs 114, 115 and 22.

(ii) Increased emissions of N_2O from the soil due to fertilizer application and changes in land use. Increases in atmospheric N_2O lead to an increase in stratospheric NO_x hence decreased ozone amounts. But with a hypothetical scenario leading to a doubling of N_2O with continuing present CFC release the net effect is not simply the linear sum of the individual impacts. This is due to the highly coupled nature of the basic catalytic cycles. With the recent changes in HO_x chemistry the estimated joint N_2O-CFC steady state depletion in total ozone is 9-17 percent while that for the doubling N_2O only scenario would be 8-16 percent, and the CFC 11-12 only scenario would be 5-10 percent.

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(iii) Increased atmospheric burdens of carbon dioxide (CO_2) could cause an increase in the stratospheric ozone amount through decreased stratospheric termperatures. Recent studies in both one-dimensional and two-dimensional models suggest that the effect of a hypothetical joint CFC-CO_2 scenario is to reduce the steady state total ozone depletion to between one half and three quarters of the value from CFCs 11 and 12 alone. In these joint scenario calculations, it was assumed that the atmospheric burden of CO_2 is eventually doubled with continued release of CFC 11 and 12 at 1977 production rates Stratospheric and tropospheric temperature changes may also affect the H_2O amount in the stratosphere which in turn will change the abundance of HO_x. However, the theoretical basis for this is too uncertain to make good quantitative estimates.

(iv) Emissions from aircraft and aerospace operations. The recent changes in the HO_x chemistry in acting to decrease the magnitude of CFC perturbations have, at the same time altered current understanding of the impact of stratospheric NO_x increases. Furthermore, NO_x emissions from subsonic aircraft, particularly in the middle and high latitudes of the northern hemisphere, may have noticeably increased the ozone content of the upper troposphere. Calculations indicate that large fleets of aircraft, whether supersonic or subsonic operating in or above lower stratospheric altitudes, would significantly deplete the ozone layer; that fleetsoperating exclusively below such altitudes would cause some ozone increases. Thus the ozone change attributable solely to existing or planned fleets would depend on their sizes and operating altitudes.

(v) Increased CO and NO_x from combustion. Such emissions may not only increase tropospheric ozone but may also change tropospheric OH. Increased emisssions from combustion may thereby influence the injection of CH_3Cl, CH_3CCl_3 and CH_4 into the stratosphere. At present, detailed information on the tropospheric budgets is inadequate to form a quantitative view.

(vi) Past atmospheric nuclear tests. Although the available modelling results and observations on the total ozone trend in the 1960's are consistent, due to the widely accepted uncertainties, this apparent agreement is judged not to be

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conclusive. If the effects on the ozone layer due to past atmospheric nuclear testing were significant, then these past events may interfere with analysis of past ozone data for the detection of other possible influences up to this time. This is yet to be fully determined.

34. At present, we are a long way from developing consistent and realistic strategies for studying all the perturbations to the ozone layer. This adds considerable uncertainty to the predicted ozone changes. Nevertheless, one should note that with an hypothetical scenario using the historical releases of CFCs 11 and 12 up to 1980 held constant thereafter, CO_2 doubling by 2050, 0.2% per year growth in N_2O concentrations and a subsonic aircraft fleet increasing by a factor of 10 between 1975 and 1990 held constant thereafter, a recent calculation shows less than a one half percent total ozone change during the next few decades in the northern hemipshere. The ozone concentration in mid-latitudes is predicted to decrease by as much as 40% at 40 km and to increase by as much as 25% at 10 km in steady state. This strong distortion of vertical ozone distribution may have a noticeable climatic impact which has yet to be analyzed.

35. Refinement of one-dimensional model structure is rapidly approaching its useful limit. Two-dimensional models overcome some of the difficulties and inadequacies of 1-D models and reveal information on the seasonal and latitudinal dependence of ozone changes. A start has been made on the inclusion of dynamical feedbacks, and these may improve the quality of the predicted ozone changes. There have been a number of recent theoretical advances in two-dimensional modelling. As yet no new practical models have appeared based on these recent theoretical developments but the prospects for progress in this, so far insufficiently studied area, appear to be good.

COMPARISON OF THEORETICAL MODELS AND MEASUREMENTS OF THE ATMOSPHERIC TRACE SPECIES

36. The first and so far the only general test of the validity of any photochemical model is the accuracy with which it reproduces the trace gas distribution in today's atmosphere. Unfortunately, a conclusive comparison between model predicted and measured trace gas distributions is limited by several factors:

(i) Although much work continues to be done, the available data are still insufficient to fully characterize the spatial and temporal variations in the stratospheric distribution of the trace gases. Except for ozone, only scattered vertical profiles are available for most trace constituents. Some important species have not been measured at all.

(ii) Due to natural variability and sometimes to experimental uncertainties, the available measurements usually only define the atmospheric concentrations within a certain error range.

(iii) Most of the measurements represent local and instantaneous concentrations whereas the models calculate concentrations which are averaged over considerable spatial and time scales.

37. Despite these limitations, the comparisons form a reasonable test at least for 1-D models, since, in their totality, the measurements place rather narrow constraints on the range of concentration values which can be assumed by the model for the various trace gas species. The models have been generally successful in describing the average vertical trace gas distributions in the stratosphere. This is especially true for some long-lived trace gases such as CH_4, N_2O, CF_2Cl_2, H_2, where the globally-averaged features are quite well described by 1-D models. With the recent availability of profiles of trace species from different latitudes, finer details may become apparent which will require multi-dimensional models for their interpretation. The existing data base is yet inadequate to provide a validation of multi-dimensional models.

38. For the short-lived species which are produced and destroyed within the stratosphere, the same situation does not generally prevail. Some measured species such as O, O_3, NO_3 and HCl show reasonable agreement between model and measurement over the altitude range of interest. Recent changes in HO_x chemistry data have helped greatly in resolving past difficulties in comparing lower stratospheric NO_2 and ClO data. New upper stratospheric NO observations are also in much better agreement with model predictions. However, the upper stratospheric distributions of HNO_3 and ClO are still difficult to understand.

39. Recent measurements of light hydrocarbons in the lower stratosphere have led to some concern about the adequacy of our understanding of the chemical partitioning among the various chlorine species.

40. In summary, it appears that present models are fairly successful in reproducing most of the features of stratospheric photochemistry as represented by the limited observations. Recent interests in developing proper interpretations and diagnostic techniques for model and experiments

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are expected to result in a new class of atmospheric observations more directly interpretable which may hence serve as better tests of models, as for example, in the recent simultaneous measurements of NO_3, O_3 and temperature.

INTERPRETATION AND EVALUATION

41. Since all models are approximations to reality, it is essential that the unquantified assumptions governing the adopted approximations should be considered along with other readily quantified parameters. Uncertainties in measured solar flux intensity, chemical kinetics reaction rate coefficients, model boundary conditions, transport coefficients, source distributions, and others can, in principle, be evaluated. Although all these parameters are not known to similar degrees of accuracy, recent progress in analysis, techniques and measurement programmes promise steady improvements in the years to come. Present analysis of the uncertainties inherent in the model predictions can only be considered as the best available information. The unquantified uncertainties, such as the possibility of missing chemistry, the adequacies of 1-D, 2-D, or 3-D model transport formulations, diurnal, seasonal or spatial averaging procedures for the non-linear interactions and the adequacy of model validation procedures, by necessity, must be evaluated partly on a subjective basis.

42. Existing views of the model's ability to describe the present day atmosphere and predict potential perturbation span the range from a high level of confidence based on the positive results discussed in previous sections to strong reservations based on the still unquantified uncertainties. The subjective components in the interpretation of model predictions will most likely persist.

43. The complementary relationship among 1-D, 2-D, and 3-D models is widely accepted, and current information strongly supports this view. Recent results from two-dimensional models on stratospheric ozone perturbation studies serve to elaborate on the seasonal and latitudinal variations of the ozone change but have not significantly altered global average predictions based on 1-D models. In addition, multi-dimensional models have pointed to new coupling processes, most notably in the troposphere, that could not have been studied with 1-D models.

44. Difficulties in 1-D model validation persist in 2-D models. This has led to new interest in re-examining the question of whether the major chemical processes in the lower stratosphere have been included in the model.

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Developments to date may affect the model predictions on CFCs effect quantitatively but not qualitatively, i.e. CFC increase leads to a decrease in total ozone.

45. The two major aspects of model predictions, past or near term trend and steady state ozone change, have different sensitivities to model input parameters In the analysis of possible trends, a major uncertainty lies in the transport parameters. Whereas for steady state changes, one additional concern is with the uncertainty of the future state of the atmosphere. Recent research interest in coupled perturbations from multiples causes has contributed a wide appreciation of the degree of complexity of this problem. Single isolated scenarios are inadequate in describing reality either past or future. Increased efforts must be devoted to assessing the most probable coupled scenarios based on world evolution in economics and culture patterns. Only model predictions based on such scenarios can be used to compare with ozone observations in testing the theory of ozone chemistry.

46. Present understanding of stratospheric ozone chemistry and transport still points to a principle of persisting effect of past emissions in stratospheric ozone perturbation. Namely, that if countermeasures were undertaken after observing a certain ozone change, the said effect would be likely to persist for decades before recovery. Further, due to the complexity of coupling among multiple perturbing influences it is difficult to provide general guidance for evaluating the possible persisting perturbing effects and its duration. The duration of perturbing influences could vary from a few years (aircraft NO_x perturbations) to several decades (CFC perturbations) to centuries (CO_2 and N_2O perturbations). Such evaluation of magnitude and duration must be performed on a case-by-case basis with the appropriate scenario.

47. A decrease in atmospheric ozone results in increased penetration to the earth's surface of the damaging short wavelength UV-B* radiation. The increase is non-linear and highly dependent on wavelength; it is the steepest for the shortest wavelengths in sunlight. Most action spectra considered in biological effects of UV, such as the DNA or erythemal or plant response action spectra, show that 290 nm photons are about four

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* UV-B 280-315 nm
UV-A 315-380 nm

orders of magnitude more effective than 320 nm photons Therefore, it is important to consider the radiation flux, wavelength by wavelength over the entire UV-B spectrum

48. Models have been developed which permit the quantitative weighting of increases in UV-B irradiance according to the various action spectra, taking into account variations in ozone column thickness, solar angle, aerosol thickness and surface albedo. The percentage change in the effective daily UV-B radiation dose produced by a one percent change in ozone column thickness is defined as the radiation amplification factor. Data shows that, in general, for biological action spectra commonly used by photobiologists, this radiation amplification factor varies from about 1.6 to about 3 for most latitudes and seasons, with the higher values existing near the polar regions.

BIOLOGICAL EFFECTS

49. If a depletion of atmospheric ozone does occur, the UV-B irradiance will increase in all areas of the world. This may have biological influences on plants, animals and man. Therefore, it is necessary to identify the biological effects to be expected and, if possible, to make quantitative assessments of these effects, especially with regard to agricultural production, fisheries and human health.

50. Effects on terrestrial plants: Higher plants have obvious importance both in agriculture and in natural terrestrial ecosystems, such as forests. Plants have evolved to expose much of their living tissue to sunlight in order to utilize its energy. Thus, a reduction of total ozone, with its attendant increase in solar UV-B radiation, could be significant for them.

51. Studies have been conducted in growth chambers, adjusted to natural daylight rhythm, in greenhouses and in the field under conditions of enhanced UV-B radiation. In spite of the different growing conditions, but under similar illumination, similar results were obtained in plant species sensitive to UV-B. Damaging effects were seen to growth parameters, leaf surface structure, composition, physiological function, pollen germination and productivity of a large variety of plant species, including many important crops, such as wheat, rice, soybeans, barley, potatoes and beans. The enhanced UV-B exposure levels at which the harmful effects began to occur depend on the sensitivity of plant species and ranged from natural sunlight levels to 50 percent enhancement of UV-B radiation. Tests of more than 100

plant species and varieties in controlled-environment growth chambers indicate that approximately 20 percent are already sensitive to present daily UV-B doses at latitudes of about 30°N, 60 percent showed intermediate sensitivity, whereas 20 percent were resistant even to UV-B doses 4 times greater than normal.

Some experiments have shown that especially early stages of growth are sensitive to additional UV-B. It has also been observed over several growing seasons that under enhanced UV-B the competition behaviour of plant species is changed, depending on the composition of the plant communities.

52. The action spectra for most of the effects of ultraviolet radiation on plants are similar to the DNA and erythemal action spectra. The action spectrum for damage to photosynthetic activity, however, differs markedly from these. It is much less steep, showing a decrease of effectiveness by only a factor of 3 over the wavelength region from 280 to 340 nm, as compared to a factor of at least 1000 for most of the other action spectra over an even narrower wavelength range

53. Non-damaging, but highly sensitive and specific UV-B effects on formations of secondary plant substances, which may act as natural protective agents, were found in many plants.

54. The environmental conditions under which many growth chamber experiments have been performed may in some cases have altered the sensitivity of plants to UV-B radiation. Before any firm conclusion can be drawn about effects on agricultural productivity, it will be necessary to conduct experiments simulating proper natural radiation conditions, both in the laboratory and in the field.

55. Effects on aquatic organisms: Solar UV-B radiations inducing biological effects have been measured to depths of more than twenty meters in clear waters and more than five meters in nuclear water. Much marine life sensitive to these UV-radiation levels (fish eggs and larvae etc.), live in the top 20 meters of ocean waters. Experimental studies with enhanced UV-B levels from zero up to fifty percent above natural levels have shown effects to fish (eggs, larvae and juveniles), shrimp, crabs, zooplankton and other plants essential to the aquatic food web. In addition, phytoplankton studies in the laboratory show that increased growth occurs when the UV-B radiation is filtered out of the incident solar radiation, indicating that existing levels of UV-B depress productivity.

56. The relative sensitivities of seven species within a selected aquatic ecosystem, studied in the laboratory under enhanced UV-B resulted in shifts of community composition. These results were corroborated by a study in a natural marine ecosystem. Studies on over 60 aquatic micro-organisms, protozoa, algae and small invertebrates, that form the base of the food web of oceanic and estuarine ecosystems, indicate that most of these, too, are sensitive to current levels of UV-B radiation incident at the water surface. More recent and more quantitative studies indicate that at doses comparable to daily levels of existing natural UV-B radiation incident at the water surface, reduction of UV-B increases the growth of chain-forming diatoms, and similarly affects the biomass and specific diversity of attached marine algae and survival of coral reef epifauna. Under conditions of enhanced UV-B radiation, decreases were observed in growth, reproduction, survival and other functions of these organisms.

57. Continued investigations concerning the range of natural ecological uncertainties, which are much larger than the uncertainties in the particular photobiological effects, will be required to assess the possible consequences for the many complex ecological interactions as well as for the productivity of fisheries.

58. Effects on human health: Considerable progress has been achieved in the study of the human health effects of increased ultraviolet radiation. Human health is influenced by UV radiation in many ways, such as the formation of vitamin D_3, sunburn, eye diseases, allergic reactions, and skin diseases including skin cancer. Among these effects, skin cancer stands out as the one problem to be significantly influenced by increased UV-B irradiance. The severity of health and other biological effects of radiation depend on its spectral composition, irradiance, and exposure time. The response may be modified by biological factors and environmental conditions. UV-B radiation has been demonstrated to be more biologically effective than UV-A radiation.

59. Epidemiologic studies have shown that the incidence of non-melanoma skin cancer correlates with exposure to sunlight; these data relate mainly to lightskinned people. Animal experiments have revealed that UV-B is the most effective wavelength region in carcinogenesis by UV radiation. These data indicate that an increased incidence of non-melanoma skin cancer is to be expected in the case of increased UV-B irradiance.

Non-melanoma skin cancer is exceptional among the biologic effects under discussion, in that numerical statistics are available. This has made it possible to make comparatively developed quantitative extrapolations. These studies indicate that, besides the radiation amplification mentioned already, there is for this particular biologic effect also a biologic amplification; for every percent increase in effective UV-B irradiance, the incidence of non-melanoma skin cancer will ultimately increase by more than 2 percent

60. There are several indications that sunlight may also be one of the causative factors in the pathogenesis of malignant melanoma, which affects people of all skin types. These indications come from epidemiologic observations which, because they deal with exposure to total sunlight, do not point to any particular wavelength range in the solar spectrum. Animal experiments indicating the effective wavelength range are not available.

Should UV-B be involved, a decrease of stratospheric ozone might be expected to increase the incidence of melanoma. This is a possibility, but it cannot be substantiated on the basis of the presently available data.

61. In studies performed on mice, UV-B radiation has been shown to alter the response of the immunological system; for instance, this results in impeded ability of the animal to reject a UV induced tumor as a foreign body, and in increased susceptibility of the animal to primary tumors induced by UV.

EFFECTS ON CLIMATE

62. Even if total ozone is not significantly changed the projected distortion of the vertical profile is expected to have climatological consequences. The projected CFC and CO_2 effects on the temperature are additive. The indicated increase of ozone concentration in the troposphere would on the other hand through modification of the IR-flux lead to a temperature rise at the surface - also adding to surface heating effect of CO_2. Therefore, increased research efforts on these problems are thus urgently needed especially in the framework of the WMO-ICSU World Climate Research Programme.

OZONE DEPLETION SCENARIOS

63. The representative of the Organization for Economic Co-operation and Development presented a report on ozone depletion scenarios being undertaken by that Organization. It was stated that during 1981, the OECD prepared a

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report on emissions scenarios for chlorocarbon releases. These scenarios, along with a single scenario for emissions of other materials affecting the ozone layer, were used as input to various one and two dimensional models of the atmosphere. The report, which includes a summary of the results of the modeling work and the discussion of that work at the meeting of an Ad Hoc Group which met in September, will be presented to the Environment Committee of the OECD in December 1981, who will determine what future work in this area will be carried out

NEED FOR REVISION OF THE WORLD PLAN OF ACTION ON THE OZONE LAYER

64. Document UNEP/CCOL/5/5, The World Plan of Action on the Ozone Layer, was reviewed, so as to determine if the requirements of the plan were still valid and complete, whether it was sufficiently detailed and comprehensive, and whether all gaps in knowledge identified in the Plan were being actively filled and at a satisfactory rate of progress.

65. Many delegations, while stating awareness of inaccuracies in parts of the original plan, in the light of new knowledge available, felt that no changes should be made to the text, but instead emphasis should be placed on the requirement, contained in the Plan of Action, to implement and further develop the Plan.

66. Several delegations considered that the CCOL had been somewhat negligent in not addressing certain aspects of the Plan as thoroughly as other sections, particularly socio-economic aspects. However, several delegations cautioned that it would be difficult to widen the scope of current and past activities of the CCOL in view of the additional cost associated with enlarging their delegations to cope with a broader Agenda.

67. It was noted that no lead agency had been designated to undertake the implementation of this section unlike other sections and one delegation suggested that OECD would be the obvious choice for this. After support for this view was expressed by others, it was suggested that UNEP should contact the OECD Environment Committee with a view to soliciting their aid in this connection. Also, UNEP will, at the time of requiring members to furnish their annual report on ongoing and planned activities, request that a report on national socio-economic measures be included.

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68. A general discussion was held to decide in which way the CCOL could best respond to the invitation of the Executive Director to contribute to the ad hoc working group of legal and technical experts planned for 20 to 29 January 1982 at Stockholm.

69. It was agreed that a small working group be established to consider this matter and to report to plenary session of the CCOL on completion of its deliberation. The report of the group is **available as document** UNEP/WG.69/7.

70. The Secretariat reported to the members on responses received from Governments to the Executive Director's letter of 21 July 1981 which requested information, including statistical and technical data, on the implementation of the recommendations contained in Decision 8/7B of 29 April 1980, in particular relating to the use of chlorofluorocarbons 11 and 12, as well as to production capacity. The Secretariat noted that thirteen replies had so far been received. The Committee was informed that a full report on this subject would be submitted to Governments in the Report of the Executive Director to the tenth session of the Governing Council in May 1982 and to the ad hoc Legal/Technical Group Meeting at Stockholm in January 1982.

OZONE DEPLETING CHEMICALS OTHER THAN CHLOROFLUOROCARBONS 11 AND 12

71. The Committee recommended that the UNEP Secretariat should collect data on chemicals, other than CFCs 11 and 12, that might affect the stratospheric ozone layer. The more important of these chemicals are identified in Section I, The assessment of ozone layer depletion and its impacts. The Secretariat was asked to report to the CCOL at its next session on the information received.

RECOMMENDATIONS FOR ACTION

72. The Co-ordinating Committee on the Ozone Layer made specific recommendations for activities relevant to the implementation of the World Plan of Action on the Ozone Layer. These were:

1. To make the Global Ozone Observing System (GOOS) based on integration of satellite and ground-based systems fully operational, and appeal for regular reporting of observational data to the relevant world centers;

2. To request UNEP to continue its support for strengthening and catalysing international activities through the WMO Global Ozone Research and Monitoring Project;

3. To intensify upgrading and intercomparisons of Dobson instruments;

4. To expand vertical ozone distribution measurements by continued balloon-borne soundings and by widely implementing "short-Umkehr" measurements as well as by encouraging the development of reliable operational satellite sensor for accurate measurements over the complete altitude range of the stratosphere including the continued development of inflight calibrations;

5. To encourage measurements of trace species of importance to the ozone question;

6. To undertake simultaneous <u>in-situ</u> measurements of the relative concentrations of photochemically related compounds of the various families;

7. To promote systematic review (using log calibration records) for homogeniety of long total ozone records;

8. To call the attention of all countries who are not yet reporting production figures of CFCs 11 and 12 as well as of other chlorocarbons to the need for reporting pertinent chemical production, release and usage data;

9. To promote studies of radiative effect of ozone and other minor species relevant to ozone photochemistry and stratospheric dynamics for detecting possible climatic impact;

10. To promote studies aimed at clarifying physical processes and phenomena having impact on error detection of ozone records;

11. To request countries to give more attention to UV-B measurements, in principle in the vicinity of ozone measuring stations as it was noted that the UV-B measurements are so far only isolated national efforts which have not been internationally standardized and integrated;

12. To continue to develop multi-dimensional models and continue to study the simultaneous effects on the various species which may perturb atmospheric ozone;

13. To continue to develop tropospheric monitoring to assess the sources, sinks, trends in concentrations of CFCs 11 and 12, chlorocarbons, N_2O and CH_4;

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14. To intensify the ongoing research on the representation of transport processes for chemical models;

15. To extend the determination of rate coefficients over the pressure and temperature ranges found in the atmosphere, and identify the products;

16. To search for and investigate any additional reactions which may affect stratospheric chemistry;

17. To continue efforts to increase understanding of tropospheric chemistry;

18. To extend measurements of the radical species to the lower stratosphere and upper troposphere using independent techniques;

19. To obtain 3-D fields of important trace constituents and meteorological variables in the stratosphere by satellites;

20. To improve knowledge pertaining to:

    (i) The relationship of dose-rate and reponse for the various biological effects of UV radiations;

    (ii) The relationship between human exposure to solar ultra-violet radiation and the development of non-melanoma, and to better define the possible relationship between sunlight and melanonia skin cancer including social and environmental conditions, as a result of these studies, global base-line data on skin cancer incidence should be established;

    (iii) The identification of high-risk groups among the populations;

    (iv) The possible interaction of chemicals, pharmaceuticals and pollutants with UV radiation.

21. To study biological effects of enhanced UV-B on agricultural crops in different geographical locations and under local growing conditions;

22. To extend aquatic effects studies to the natural water environments in order to gain knowledge of the resultant effect of enhanced solar UV-B radiation on aquatic food productivity;

23. To continue studies on biological action spectra and the spectral response using also polychromatic radiations in order to include possible interactions of the various wavelength regions;

24. To include photorepair, adaptation and protection mechanisms in the overall considerations of UV-B effects;

25. To determine the influence of existing and enhanced UV-B radiation on:

    (i) The sensitivity and activities of insects important to the biospheric balance (animal food chain, plant cross-fertilization, etc.);

    (ii) Micro-organisms, such as those causing plant and animal diseases;

    (iii) Primary processes such as photosynthesis, biosynthesis, etc.;

    (iv) The photodegradation of herbicides, pesticides, fertilizers and similar agricultural chemicals;

    (v) The effects of other stress situations.

26. To determine the mechanisms by which UV-B radiation acts on biological species and eco-systems;

27. To promote the publishing of manuals providing guidelines for both UV-B exposure studies and to facilitate intercomparison of biological research results;

28. To develop improved individual and biological UV-B dosimeters.

An executive summary of the assessment and the recommendations of the ... CCOL is attached as Annex 1.

ANNEX I

EXECUTIVE SUMMARY

The United Nations Environment Programme's Co-ordinating Committee on the Ozone Layer (CCOL) met in Copenhagen 12-16 October 1981 for its fifth session. The Committee examined the substantial contributions presented to it by various countries and organizations and the research efforts in observations, evaluations and modelling necessary for the study of the stratosphere. On the basis of existing and new information available the Committee concluded the following:

1. A risk of depletion of the ozone layer due to chlorofluorocarbon releases is still most likely, although natural variations and other compounds which may affect ozone, require increased consideration.

2. If one considers only chlorofluorocarbon 11 and 12 releases at their present rates, current model calculations estimate an eventual ozone reduction in the range 5 to 10 per cent, compared to about 10 per cent estimated in last year's CCOL report. The change from the 1980 figure is due to new data on certain chemical reaction rates. If present releases of other chlorocarbons are continued at present rates, then they could increase the eventual ozone depletion due to CFC 11 and 12 alone by about one third.

3. Recognizing the simultaneous and complex impacts of human activities on atmospheric ozone, more realistic scenarios have been developed to study the coupled nature of potential ozone changes. The changes in the trace gas concentrations of N_2O, NO_x and CFC's may have all affected the past ozone amounts. The estimate of the present total column ozone depletion is less than one per cent, which is below the present detection limit.

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4. The relatively large natural variability of atmospheric ozone makes detection of long-term trend difficult. Consistent with the study using multiple scenarios from historical data, no evidence of changes in total ozone has been observed. This recognises the significant continuing progress made in statistical analysis of the ozone record.

5. Observational data indicate an ozone increase in the northern hemisphere troposphere over the last 10 years which is qualitatively consistent with the model predicted impact from past subsonic aircraft operations and other combustions. Observations in the upper stratosphere are still inadequate to validate the model predicted changes due to CFC 11 and 12 releases in the past decades. Multiple scenario models suggest that the distortion of the vertical ozone profile might become more important than changes in the total amount with respect to possible climatic consequences.

6. Continued improvement of the data base or atmospheric trace species has contributed to the resolution of some past problems in interpretation and pointed out new areas of possible concern.

7. World production of CFC's 11 and 12 combined as estimated by the Chemical Manufacturer's Association has fallen by a total of 18% between 1974 and 1980. Most of the decrease occurred in the years 1974 to 1977; only 1% decrease took place in the past year (1980). Uses in aerosols have declined but other uses, for example in foamed plastics and air conditioners, have shown an increase. It is recognized that eventually reduction of CFC used in aerosols could be offset by growth in non-aerosol uses. There are also indications of increased production of other chlorine containing compounds which could affect the ozone layer.

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8 If atmospheric ozone decreases, more solar ultraviolet radiation, in the UV-B range, will penetrate to the earth's surface. New studies have confirmed previous estimates of the relation between ozone decrease and UV-B increase. The health and biological effects to be expected from such an increase of ultraviolet radiation formed one of the main topics of discussion at the meeting. Most of the known effects of UV-B are damaging effects, so that there is concern for the consequences, especially with regard to agricultural production, fisheries and human health.

9. Recent research results indicate that many terrestrial plants and aquatic organisms may undergo damage by increased UV-B; this applies to important crops such as wheat and rice, and to aquatic organisms such as fish eggs and larvae. Further investigations are needed, however, to assess the overall effects under the complicated actual growth conditions.

10. With regard to human health, it is well-established that an increase in solar UV-B would lead to an increased incidence of non-melanoma skin cancer, especially in light-skinned people.

There are several indications that sunlight may be one of the causative factors of malignant melanoma, which affects people of all skin types. It is presently not known if UV-B is involved; should it be involved, a decrease of atmospheric ozone might be expected to increase the incidence of melanoma.

11. The Committee emphasized the importance of member countries and international organizations as WMO, with the support of UNEP to provide pertinent chemical production, release, and usage data and to continue to collaborate in studies on the ozone layer.