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Submitted by

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on the Ozone Layer

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POSSIBLE EFFECTS OF MAN'S ACTIVITIES ON THE OZONE LAYER AND CLIMATE

INTRODUCTION

1.1 The purpose of this short document is to present a summary of our present understanding of the changes to the ozone layer and the earth's climate which may result from human activities.

It is a distillation of the 1986 CCOL part 1 report, attempting to identify key issues of interest to the policymaker. It is anticipated that companion documents to this one will arise from the CCOL Part 2 (Effects) conference and the Economics Workshops.

OZONE IN THE EARTH'S ATMOSPHERE

2.1 The atmosphere of the earth can be divided into several layers; the two that are of main concern to us are the TROPOSPHERE, which stretches from ground level to about 12km and is the region containing our weather, and the STRATOSPHERE, which extends from the top of the troposphere up to about 50km. (Figure 1).

2.2 Ozone (O3) is a form of oxygen, and is present throughout the atmosphere; about 90% of it is in the stratosphere and 10% in the troposphere. It reaches its maximum mixing ratio (proportion of the air) between about 20km and 30km, (at the parts per million level) in a region often referred to as the STRATOSPHERIC OZONE LAYER.

2.3 It is important to distinguish between ozone in the troposphere, where increasing emissions of hydrocarbons and nitrogen oxides may be causing levels to rise, and ozone in the stratosphere. In both cases the ozone is created photo- chemically (that is, it needs sunlight) but the chemical processes are different. Although stratospheric ozone can descend to the troposphere and increase levels of ozone there, tropospherically created ozone does not ascend to the stratosphere.

2.4 There are two consequences of the presence of ozone in the troposphere. Firstly it has the potential to affect human health and the environment; this report will not consider that aspect. Secondly it can act as a greenhouse gas, and this will be considered further in Section 11.

2.5 Ozone throughout the atmosphere absorbs solar ultraviolet light, and controls the amount of it reaching the earth's surface, where it has the potential to affect human health and the environment. The amount of absorption depends upon the total amount of ozone present in the whole depth of the atmosphere (i.e. troposphere plus stratosphere), which is sometimes called TOTAL OZONE or COLUMN OZONE. It is this quantity which is usually referred to when we speak of 'ozone depletion'.

2.5 The vertical distribution of ozone is also important, because any change in it can affect the temperature structure of the atmosphere and could influence global climate.

FACTORS WHICH DETERMINE STRATOSPHERIC OZONE LEVELS

3.1 Ozone is continually created naturally in the stratosphere when ultraviolet light from the sun acts on the oxygen molecules there. It is continually destroyed naturally in a number of interrelated chemical cycles involving oxygen, hydrogen, nitrogen and chlorine compounds,which are present in the stratosphere due to emissions, both natural and man-made, at the earth's surface. These gases act as CATALYSTS; a molecule of chlorine, for instance, once it has taken part in an ozone destroying cycle, will emerge unscathed to take part in many more cycles, before it becomes chemically inactive. In this way abundances of chlorine and nitrogen at the parts per billion level can influence parts per million abundances of ozone.

3.2 The amount of ozone in the stratosphere is a result of a balance between sources and sinks, ie generation and loss processes. The rate of production of ozone is controlled by solar output, and not significantly affected by human activities. However the magnitude of the sinks is determined by emissions of several TRACE gases, in particular CHLOROFLUOROCARBONS (CFCs), METHANE (CH4), NITROUS OXIDE (N2O), and CARBON DIOXIDE (CO2), the abundance of which are all observed to be increasing.

3.3 BROMINE is also a very efficient catalyst of stratospheric ozone destruction. Its present concentration,(dominated by natural sources) is low, and therefore its effect on ozone is only a few percent of that of chlorine. However, its concentration is increasing rapidly (due to industrial sources such as fire extinguishants) and, were this increase to continue, bromine may become relatively more important.

3.4 Any change in the rate of emissions of these trace gases has the potential to affect ozone levels, and so the effect of these changes must be fully investigated. Since experiments can obviously not be carried out in the real atmosphere, the only way to predict changes is to use a mathematical model run on a computer. Such models contain a representation of the complex chemical reactions and physical processes (eg meteorology) found in the real atmosphere

CHANGES IN CONCENTRATIONS OF PRECURSOR GASES

4.1 CFCs (see footnote) are totally industrial in origin; trends in production are shown in Figure 2, together with estimates of emissions. Use of CFCs in aerosol sprays declined substantially from the early 1970's, but has levelled off more recently. Non aerosol use has continued to grow uninterrupted. Currently, most CFC production is released to the atmosphere.

(Footnote: References to "CFC" in this document should be taken to mean the sum of CFC11 and CFC12, except where expressly stated)

4.2 There are no known destruction processes for CFCs in the troposphere, where most of them reside. They diffuse up to the stratosphere over a period of a few years, where they are destroyed by sunlight to produce the active chlorine which can take part in ozone- destroying cycles.

The lifetime of CFCs in the atmosphere is about 100yrs. Consequently, if there is a change in stratospheric ozone caused by increasing atmospheric concentrations of these gases, the recovery of the system will take several tens to hundreds of years after the termination of emissions.

4.3 The concentration of CFCs 11 and 12 in the troposphere is shown in Figure 3. The large rate of increase reflects the fact that concentrations have not yet reached a "steady state" in the atmosphere, ie they are still being emitted at a faster rate than they are disappearing by diffusion and destruction in the stratosphere. This point is well illustrated by observing that atmospheric concentrations of CFCs (Figure 3) continued to rise between 1974 and 1980 when emissions actually decreased.

4.4 CFC11 and 12 are currently the most important contributors to stratospheric chlorine. However there are a number of other chlorine containing compounds which together contribute about 25% of chlorine in the stratosphere due to man made compounds. The atmospheric concentrations of some of these other compounds, notably CFC22, CFC113 and CH3CCl3(methyl chloroform), are increasing at 7 to 10% per year.

4.5 The way in which the chlorine content of the stratosphere, (an important quantity in ozone depletion calculations), will change due to different CFC emission rates, is shown in Figure 4. If CFC emissions were to be held constant at current rates then eventually chlorine will reach about 8ppb. At a constant rate of double today's, chlorine will reach about 15 ppb. These figures assume a background of about 1ppb due to the emission of natural chlorine compounds.

4.6 METHANE concentrations are rising at about 1% per year (Figure 5). The main sources of this increase are thought to be rice production and cattle. Methane is lost when it reacts with other species in the troposphere, and this reaction may have been slowed down due to increasing levels of CARBON MONOXIDE (CO), from man-made sources. It is not clear to what extent the upward trend in methane levels is due to increasing emissions, decreasing loss, or both. The lifetime of methane in the atmosphere is about 10 years.

4.6 Concentrations of CARBON DIOXIDE are increasing at about 0.5% per year, principally due to increasing emissions from combustion of fossil fuels. Figure 6 shows measurements made at one site for more than 20 years; similar long term trends are observed globally.

4.7 NITROUS OXIDE is the main source of nitrogen in the stratosphere. Sources of N20 are both natural and anthropogenic with the latter (principally agriculture and combustion) the major contributor to the increase in source strength. The upward trend in concentration, shown in Figure 7 , is about 0.25% per year. N20 has a lifetime of about 150 years in the atmosphere.

MODELLED PREDICTIONS OF THE EFFECT ON OZONE OF PRECURSOR GAS CHANGES

5.1 In a real future atmosphere concentrations of all these gases will change, and models are used to calculate the effect on ozone of these "multiple purturbations". However, it is instructive to consider HYPOTHETICAL increases in each of the trace gases singly.

as an illustration of the relative influence that each has on ozone cycles.

Figures 8 to 11 show the change to the global average ozone profile which is predicted to occur when the emissions or concentrations of each of these trace gases are changed, leaving all of the other gases constant; Figure 8 for CFCs, Figure 9 for methane, Figure 10 for N2O, and Figure 11 for CO2.

5.2 The column ozone depletion associated with each of the perturbations in figures 8 to 11 is shown in Figure 12. In terms of column ozone, increases in CFCs and N2O both lead to a calculated decrease in ozone, but increases in methane and CO2 both lead to an increase in ozone. In the case of CO2, this increase results from a change in the temperature profile, rather than from changes in chemical composition. The heights at which these changes take place are very different, as can be seen from the Figures 8 to 11.

5.3 As stated earlier, in a real future atmosphere concentrations of all these gases will change, and so the models are used to calculate the effect on ozone of these "multiple perturbations". First of all we need to make a prediction of how the atmospheric burden of the trace gases will change. Because we do not fully understand the reasons why CH4 and N2O are increasing, it is expedient for analytical purposes to assume the continuation of present trends, and in all the "multiple perturbation" scenarios considered herein , this assumption is adopted.
For CO2, we assume the central USDoE scenario of about 0.5% increase per year.

5.4 For CFCs the emissions are determined by economic activity, and the effect of three different growth rates is considered: zero (ie continuing emissions at 1980 levels), 1.5% per year compound and 3% per year compound; the latter equivalent to a doubling of production every 25 years. These three scenarios are labelled A,B and C respectively.

5.5 We look at the predicted changes in total ozone under each of these scenarios in Figure 13. Scenario A would result in essentially no total ozone change, because the depleting effect of CFCs would be offset by the enhancement effect of methane and, to a lesser extent, CO2. Ozone column changes are calculated to be less than 3% over the next 70 years for CFC emission increases of less than 1.5% per year, but with a sustained CFC growth rate of 3% per year, the predicted ozone depletion after 70 years is 10% and rapidly increasing.

The choice of trace gas scenario is crucial; if methane fails to continue increasing at 1% per year, for instance, then total ozone would deplete more rapidly. If methane concentrations rise even more quickly, then total ozone would be depleted less rapidly.

DEPENDENCE OF OZONE DEPLETION ON ALTITUDE AND LATITUDE

6.1 Predicted changes in total ozone conceal the fact that they are a combination of large percentage decreases at about 40km, (predominantly due to CFCs- see Figure 8), added to large percentage increases mainly in the troposphere (predominantly due to methane - see Figure 9) This is illustrated in Figure 14, using a CFC growth scenario of 1.5% per year.

6.2 Two dimensional (altitude and latitude) models give us the capability to investigate latitudunal and seasonal dependence of ozone depletion. Results so far discussed in this summary have been from one dimensional (altitude only) models.

It is significant that calculated column ozone depletion will be greater at high latitudes than close to the equator. Figure 15 shows that, for zero growth in CFC emissions (with continuing growth in methane and N2O, but with no growth in CO2), the percentage decreases at 80 degrees N, during springtime when the effect is a maximum, are predicted to reach 11% by 2030.

Calculations are now being performed with the addition of CO2 increases, to see if the ameliorating effect predicted by one dimensional models is observed.

RECOVERY OF TOTAL OZONE

7.1 There is concern over the extent to which (because of the 100 yr lifetimes of the CFCs) ozone will continue to deplete even after CFC emissions are reduced. In Figure 16a the change in total ozone is predicted for CFC growth rate scenarios A and C as above, using the previously described two dimensional model. In Figure 16b, the change in total ozone is predicted for the constant release of CFCs at 1980 levels, but assuming methane also remains constant at its 1980 level (scenario Ao)

7.2 Added to each is a branching curve A',C' and Ao' describing how ozone will change following a hypothetical complete cessation of CFC emissions in the year 2000. It is seen that, in all scenarios, depletion continues for a further 5 - 10 years, but the "overshoot" is less than one percent, before a slow recovery begins. Of course, overshoot and recovery time will be greater if CFC emissions are reduced rather than terminated completely.

7.3 The rate of recovery of total ozone is quite sensitive to the assumed scenario for methane. From Figures 16 a and b it can be seen that the recovery is much more rapid when methane levels continue to increase.

LINEARITY

8.1 Recent, improved, two dimensional models have demonstrated that

that ozone depletion remains linear until levels of at least 25ppb chlorine in the stratosphere are reached. These levels would not be reached, even with a 3% growth rate in CFC emissions, for the next eighty years. Thus the "chlorine catastrophe" is not now thought to be a danger.

OZONE OBSERVATIONS.

9.1 All the preceding discussion deals with modelled predictions of ozone. Measurements of total ozone have been made from a global network of groundbased instruments (Dobson) for many years. Despite considerable variability on many timescales, a statistical analysis shows that no significant trend in total ozone has occured between 1970 and 1984. This is consistent with model calculations in which changes of all trace gases have been considered.

9.2 Groundbased measurements of ozone at 40km do indicate a small downward trend, 2-3% since 1978. This is also consistent with model predictions. However, there are reservations about the quality of the observational data.

9.3 Over Antarctica, there has been a large decrease in column ozone during early spring (Sept - Oct) by about 40% since 1960 - most of this occurring since the mid-70's. Figure 17 shows the amount of column ozone for October over this period. In addition, satellite monitoring has also demonstrated significant decreases extending out to latitudes of 45 degrees S. A decrease is not evident anywhere north of 45 deg S.

Existing models did not predict, neither are they able to explain, this depletion; it may be chemical in origin or due to changes in atmospheric circulation. Until it is understood, we cannot assess whether it is a precursor of a global effect, or whether it will always be confined to the Antarctic due to the special conditions that exist there. A better understanding of this phenomenon is being vigorously pursued, using theoretical and experimental approaches.

UNCERTAINTIES AND CONFIDENCE IN PREDICTIONS OF OZONE DEPLETION

10.1 Uncertainties in predictions of ozone changes arise from two causes;
(a) the quality of models
(b) uncertainties in future predictions of trace gas abundances

10.2 The predictions of atmospheric change rely on mathematical models. A primary test of the models is their ability to simulate the features of the present atmosphere, which are being observed in some detail in the current measurement programmes. Most of the key atmospheric constituemts have been observed. Disagreements between observations and simulations of key species do appear, which places limits on our confidence in the predictive capability of models. However, in general, there is agreement between observed concentrations and their simulations.

10.3 Even if the models were perfect, the predictions of ozone depletion would be correct only if our assumptions of the future atmospheric abundances of trace gases were correct. For CH4, CO2 and N2O, the best guess is for a continuation of present trends; but

this is not based on an understanding of sources and sinks and how they might change.

10.4 The pace of progress towards the resolution of these uncertainties is difficult to predict. Apart from a steady progress brought about by continuing research (at a rate determined by resources) we may expect some accelerated progress arising from a detailed study of the Antarctic "ozone hole" following large experimental campaigns in 1986 and 1987. The results from advanced atmospheric probes to be flown on the UARS satellite in 1991, will represent a massive increase in observations of many of the trace species involved in ozone chemistry, and enable validation of models to be advanced considerably.

10.5 Uncertainties in the future growth of trace gases will diminish as our understanding of global tropospheric chemistry mounts as a result of the large experimental programmes now being planned for the late 1980's.

GLOBAL WARMING DUE TO INCREASED CONCENTRATIONS OF TRACE GASES

11.1 All the trace gases discussed so far, and which play an important role in controlling abundances of stratospheric ozone, can separately inflence climate through their physical properties as greenhouse gases. They transmit solar radiation to earth (and thus, allow it to be warmed) but block infra-red radiation from leaving the earth, which prevents it from cooling. Increased concentrations of greenhouse gases will lead to a rise in the surface air temperature of the earth - the "global warming".

11.2 In addition, ozone itself is a greenhouse gas, and will add to the effect on global climate of the other trace gases.

11.3 The relative contribution to global warming due to equal absolute increases in each of the trace gases already discussed (CFCs, CO2, CH4, N2O) is straightforward to calculate and is illustrated in Figure 18. In order to make predictions of the magnitude of a global warming, we obviously have to multiply the effect of each trace gas by the rise in its concentration which we expect; hence, we have to adopt a scenario for these rises. This is demonstrated in Figure 19, which shows the global temperature change predicted to be caused by each greenhouse gas, according to its concentration in the year 2030, adopting a scenario where CFCs grow at 3% per year, CO2 grows at approximately 0.5% per year, and N2O and CH4 grow at present rates (0.25% and 1% per year respectively). The temperature changes due to each are directly additive, giving a total global warming (increase in surface air temperature) of about 3 degrees (+-1.5deg) Celsius by 2030.

Under this scenario, about half of this warming would be due to CO2, and the other half due to other trace gases.

11.4 If it were not for the effect of the oceans, this temperature rise would have ocurred by the year predicted (ie 2030). But the thermal inertia of the oceans will delay the realisation of any warming by some tens of years. Thus, in the year 2030, perhaps half of this 3 degree temperature rise will have already ocurred, with the other half yet to ocurr over the next few decades, even with no further increase of greenhouse gas concentrations after 2030. This concept of "realised" and "to-be realised" temperature rises has policy implications, particularly when taken together with the long residence times of some greenhouse gases.

11.5 Temperature changes of this magnitude, within this time frame, are thought to have significant implications for global and regional climates.

11.6 The surface air temperature response is not thought to be globally uniform, but is magnified at high latitudes snd is somewhat muted at low latitude, in comparison to the global mean response. In addition studies also indicate significant zonal

variations at all latitudes, even in tropical regions.

MEASURED TRENDS IN GLOBAL SURFACE TEMPERATURES

12.1 Observations gathered over the past century have been analysed to show the way in which the surface temperature in the Northern Hemisphere has varied in that time; Figure 20 shows this. As with ozone, the year-to-year variability makes the identification of any trend very difficult, but statistical analyses indicate an upward trend amounting to about 0.5 degrees Celsius over the period; this is not inconsistent with the calculated rise expected from present day CO2 and trace gas concentrations but does not provide any adequate confirmation of the validity of the calculations.

UNCERTAINTIES AND CONFIDENCE IN CLIMATE PREDICTIONS

13.1 The uncertainty in predicting global surface warming stems from the inability of current models adequately to treat the full complexity of physical processes in the real atmosphere. We know that there are several feedback mechanisms (which can act to amplify or reduce the effects) which are poorly represented in current models. Consequently, although we can be sure that a warming will occur, its magnitude and timing is far from agreed. An uncertainty of plus or minus 1.5 degrees usually accompanies the figure of 3 degrees quoted above; ie a range of 1.5 to 4.5 degrees Celsius.

13.2 This range, however, only refers to uncertainties in the modelling process. As with ozone depletion, the future of trace gas concentrations is a major determining factor. Until we understand the role of the biosphere in regulating emissions, the probable future release rates of industrial gases, and the relationship between these emissions and trace gas concentrations, our confidence in projecting current rates of change into the future must be limited.

Document drafted during ad-hoc meeting at DoE London, 13/14 Aug 1986

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G Jenkins
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P Bakken
W Garber

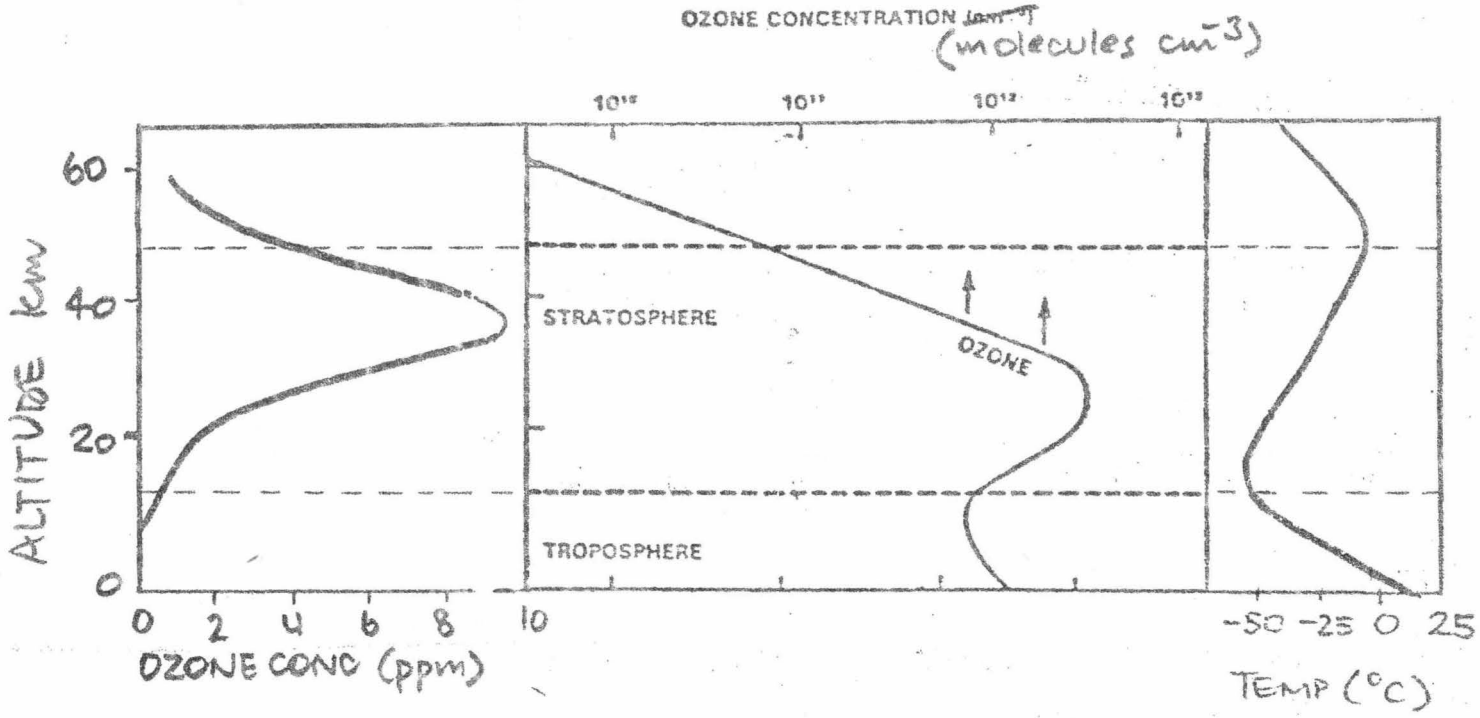
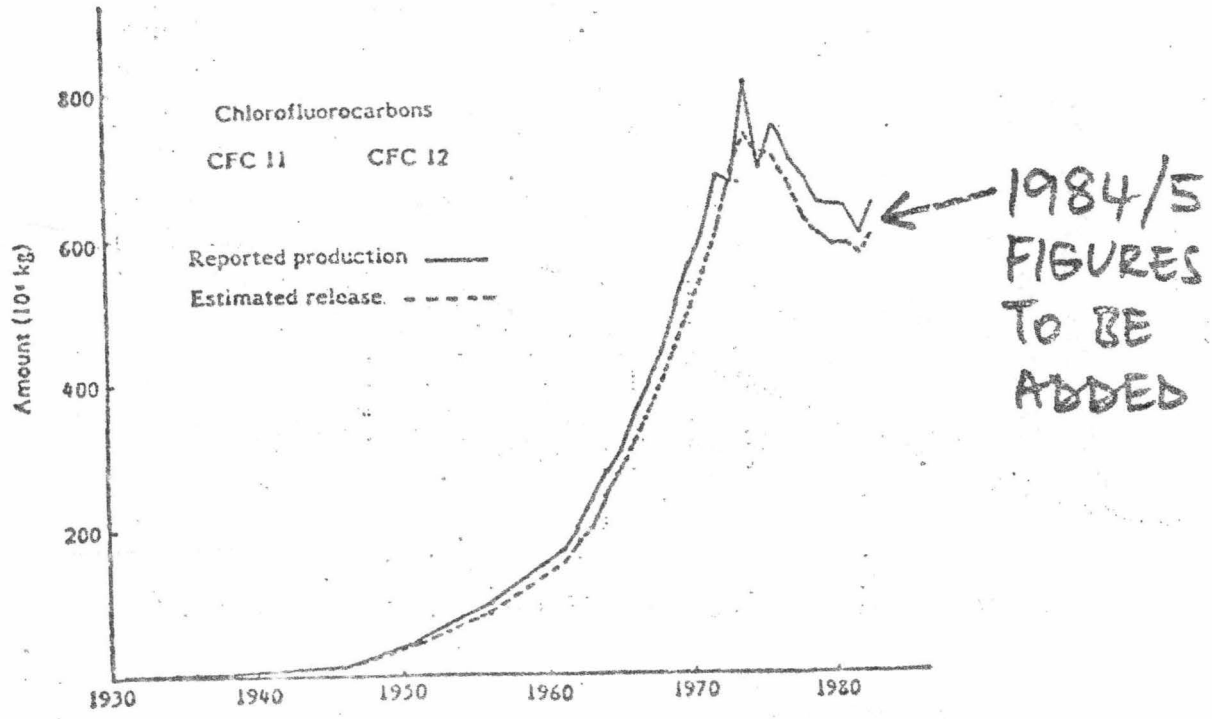


FIGURE 1 Temperature profile and ozone distribution in the atmosphere

[REVISED DIAGRAM FROM BOB WATSON]



Production and release of chlorofluorocarbons to the atmosphere
Source Chemical Manufacturers Association

FIGURE 2

CHANGES IN PRECURSOR GASES — I

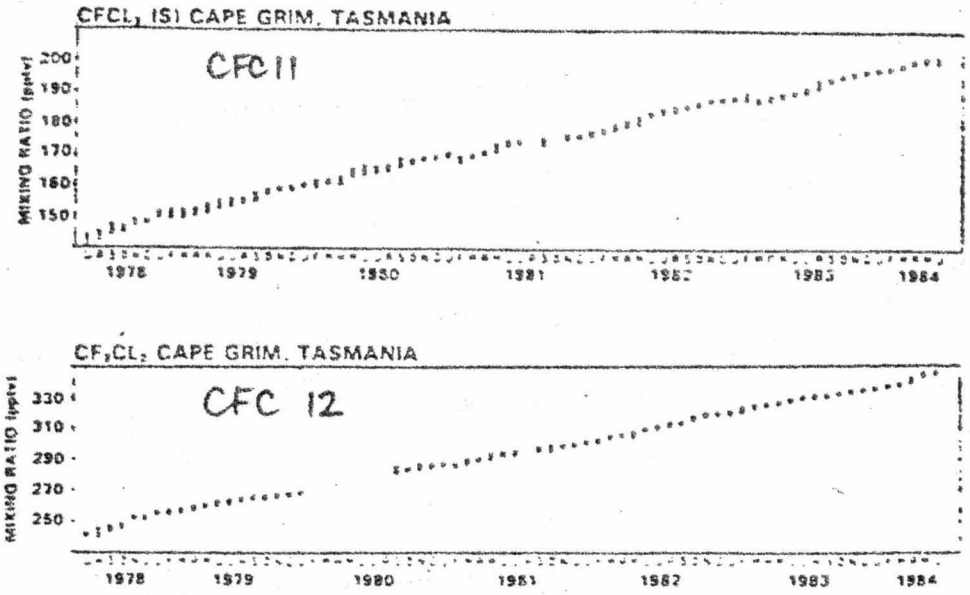


FIGURE 3

ATMOSPHERIC CONCENTRATIONS OF CFC 11 AND CFC 12

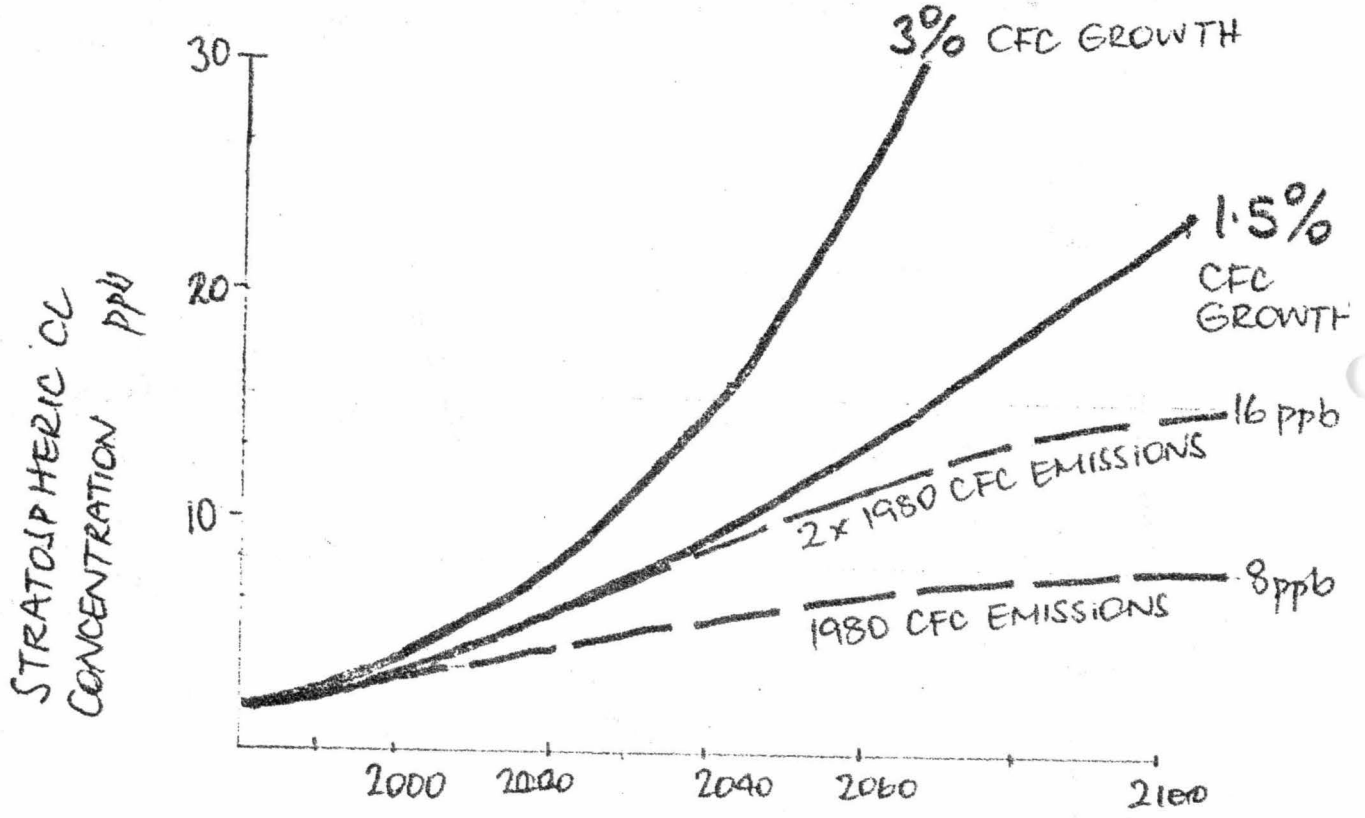


FIGURE 4

RELATIONSHIP BETWEEN CFC EMISSIONS AND STRATOSPHERIC Cl CONCENTRATION

CHANGES IN PRECURSOR GASES - II

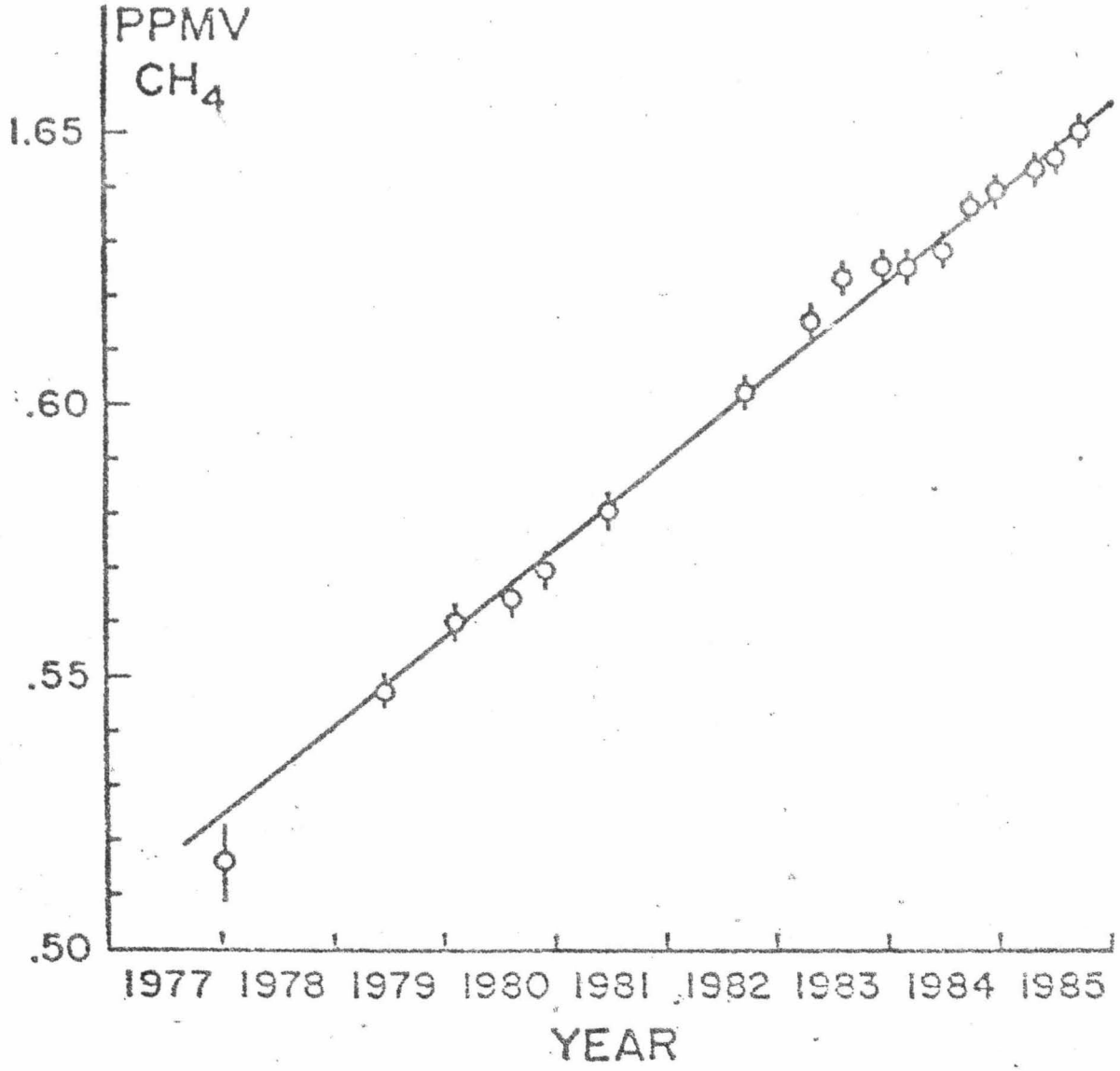


Figure 5 Globally averaged concentrations of CH_4 from 1977 to 1985 (Rowland)

FIGURE 7
TRENDS
IN N2O

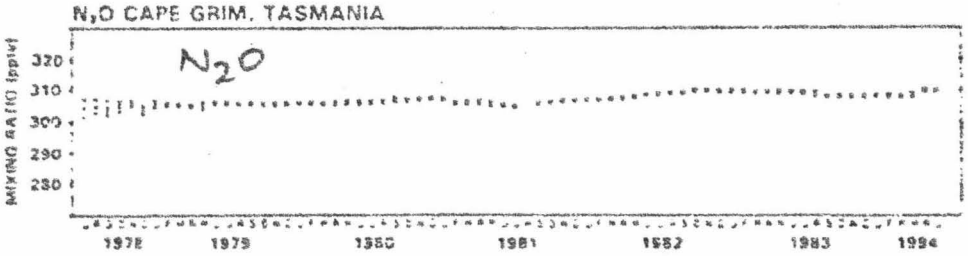


FIGURE 6
CO_2

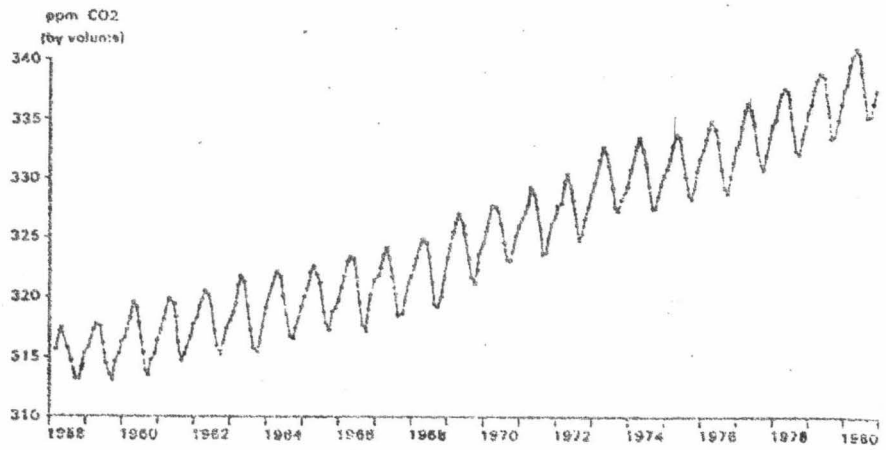


Figure
Monthly average carbon dioxide concentrations at Mauna Loa Observatory

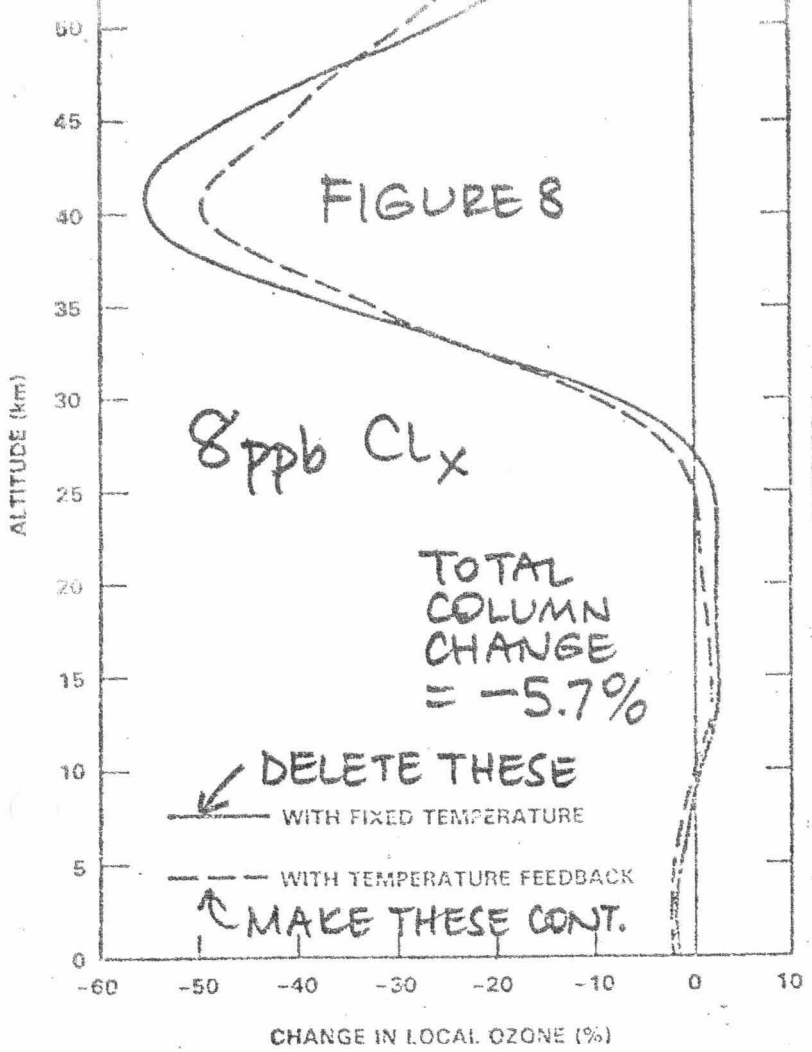


FIGURE 8

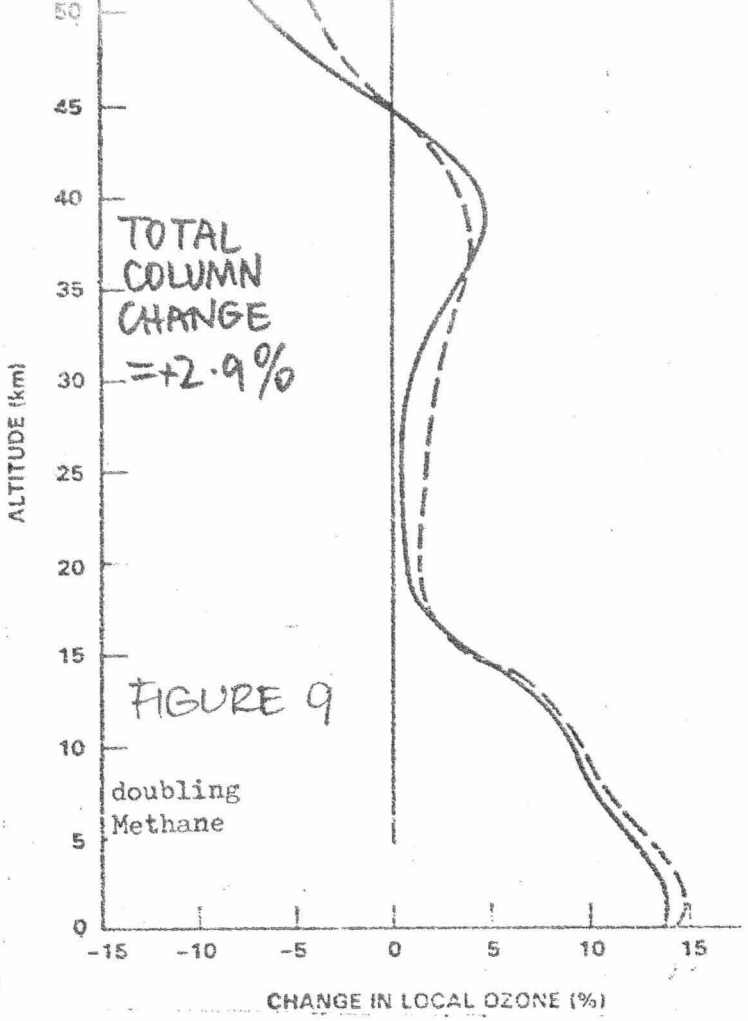


FIGURE 9

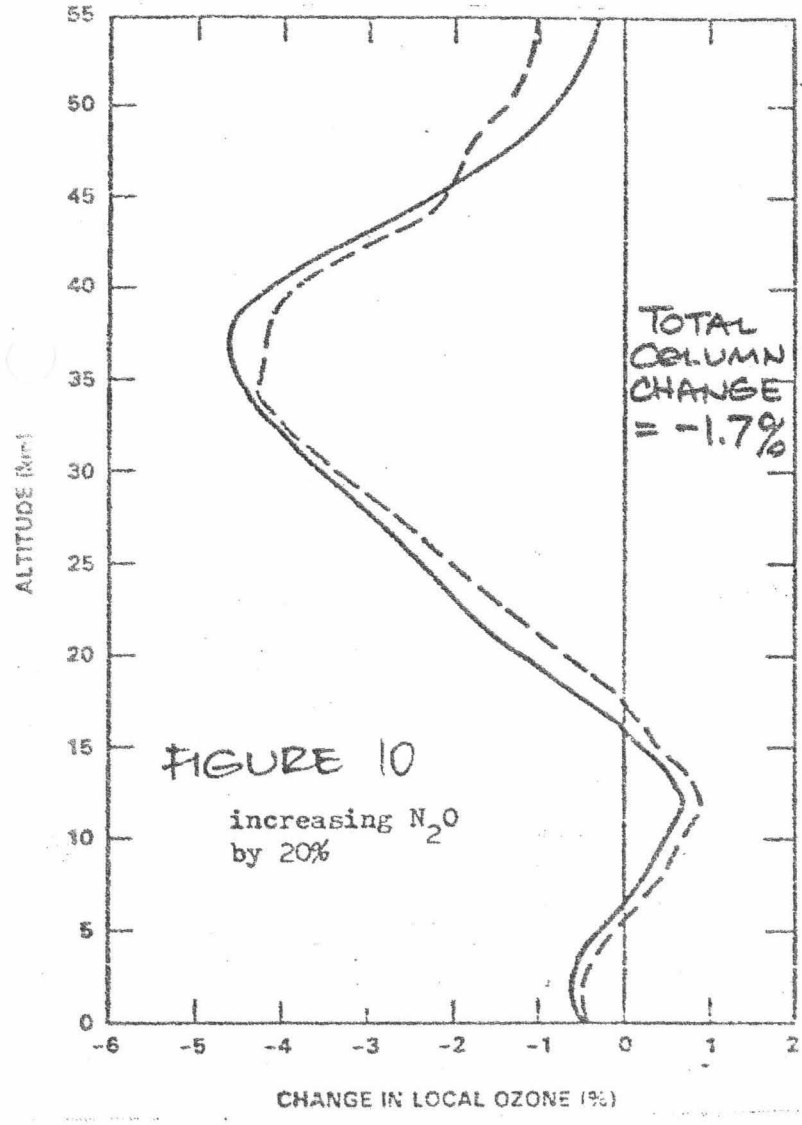


FIGURE 10

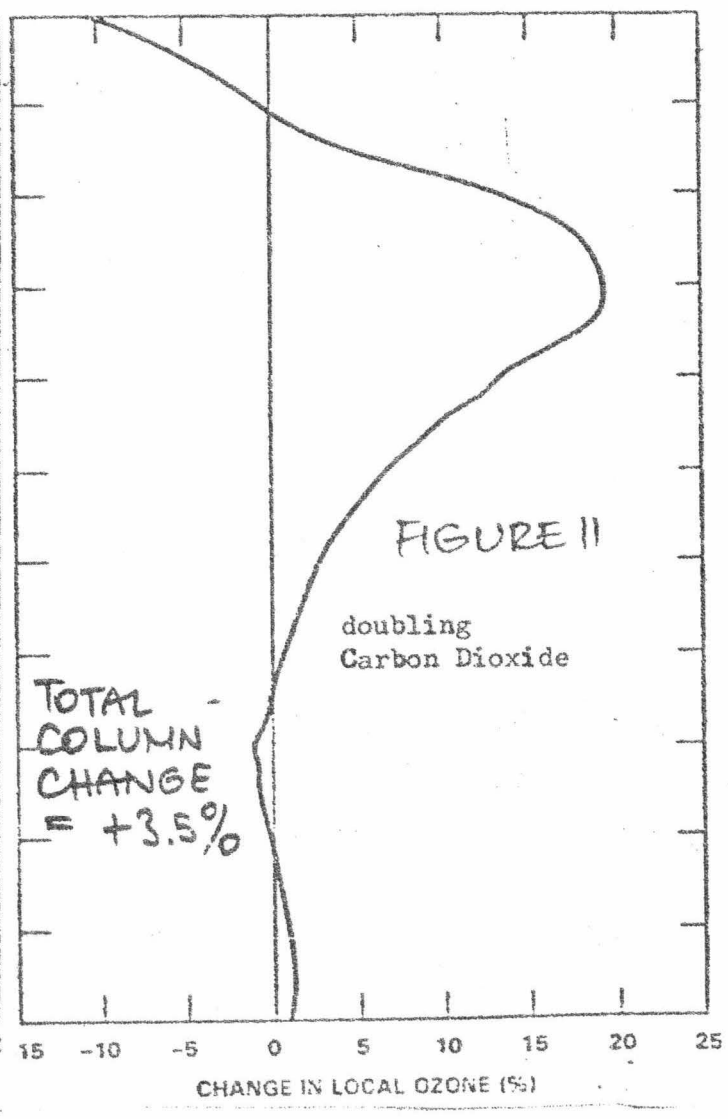


FIGURE 11

THESE MODELS HAVE ALSO BEEN USED TO MAKE MULTIPLE GAS SCENARIO PREDICTIONS. THE LAWRENCE LIVERMORE MODEL, FOR EXAMPLE, PREDICTS THE FOLLOWING STEADY STATE PERCENTAGE LOSSES IN COLUMN OZONE FOR THE FOLLOWING ATMOSPHERIC COMPOSITION CHANGES.

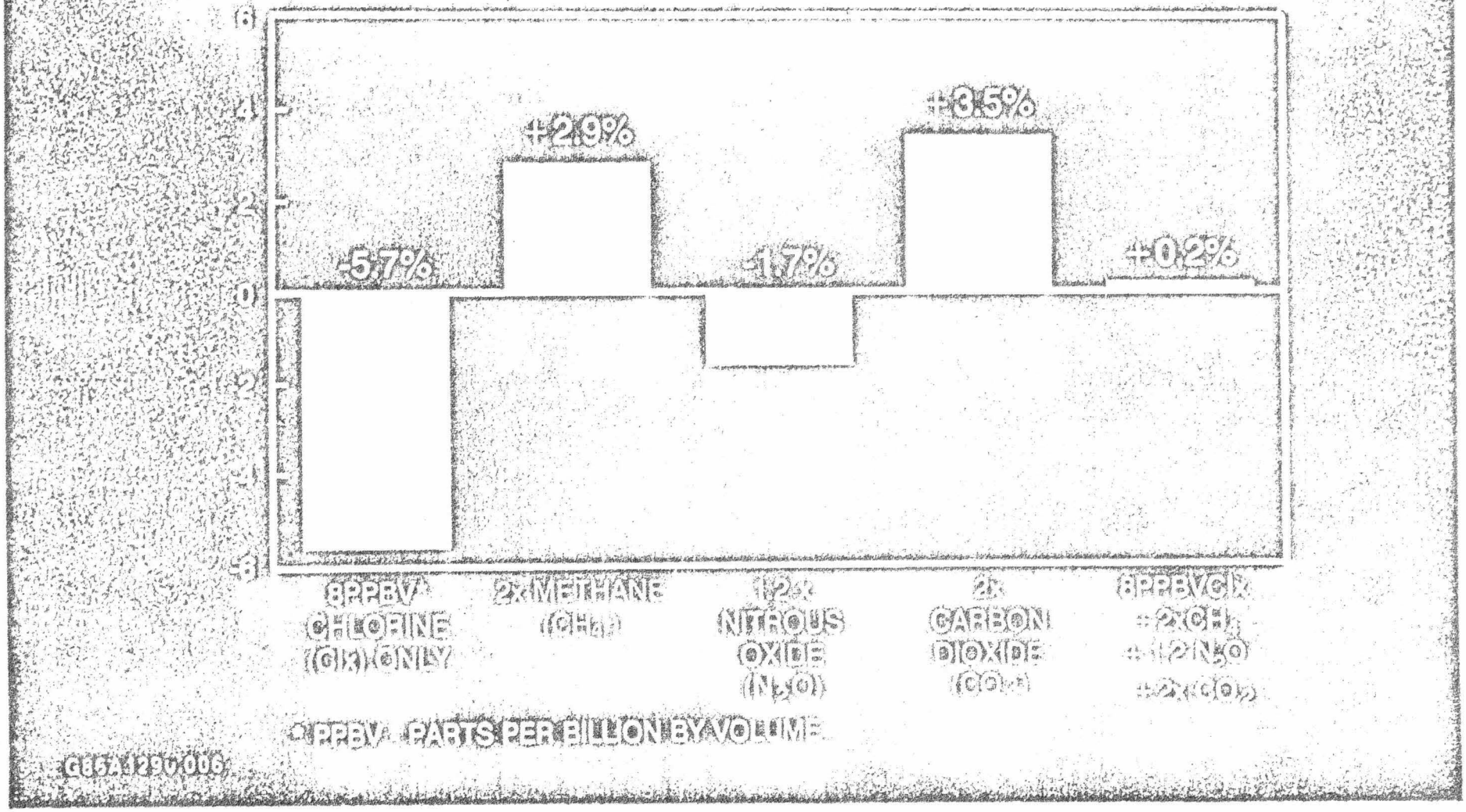


FIG 12

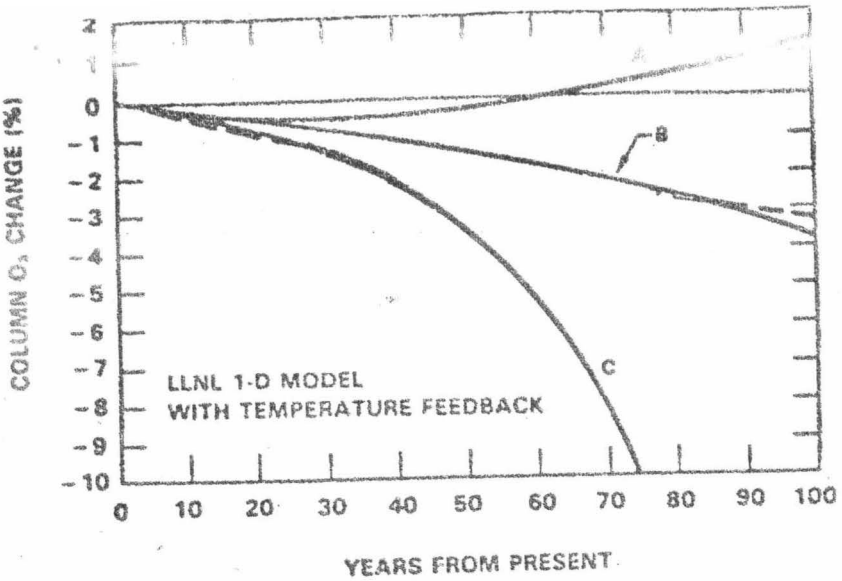
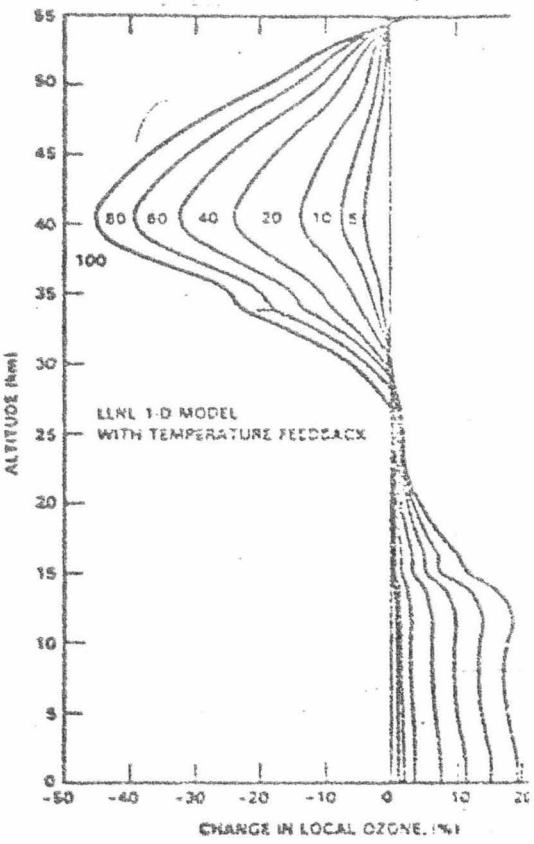


FIGURE 13

FIGURE 14



BOB WATSON WILL ASK WEUBBLES FOR ADDITIONAL CURVES SHOWING ABSOLUTE CHANGE. →

DELETE EVERY OTHER CURVE →

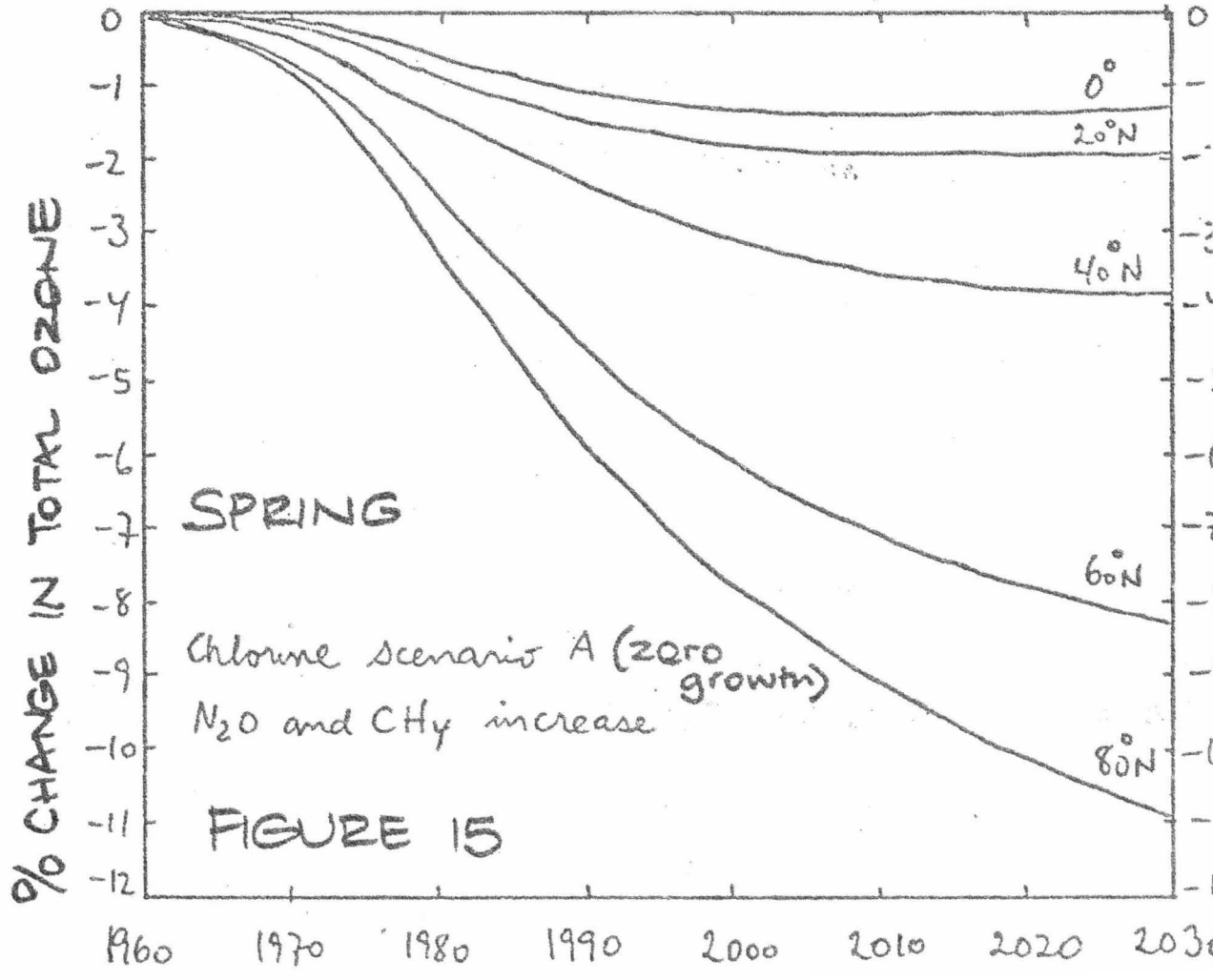


FIGURE 15

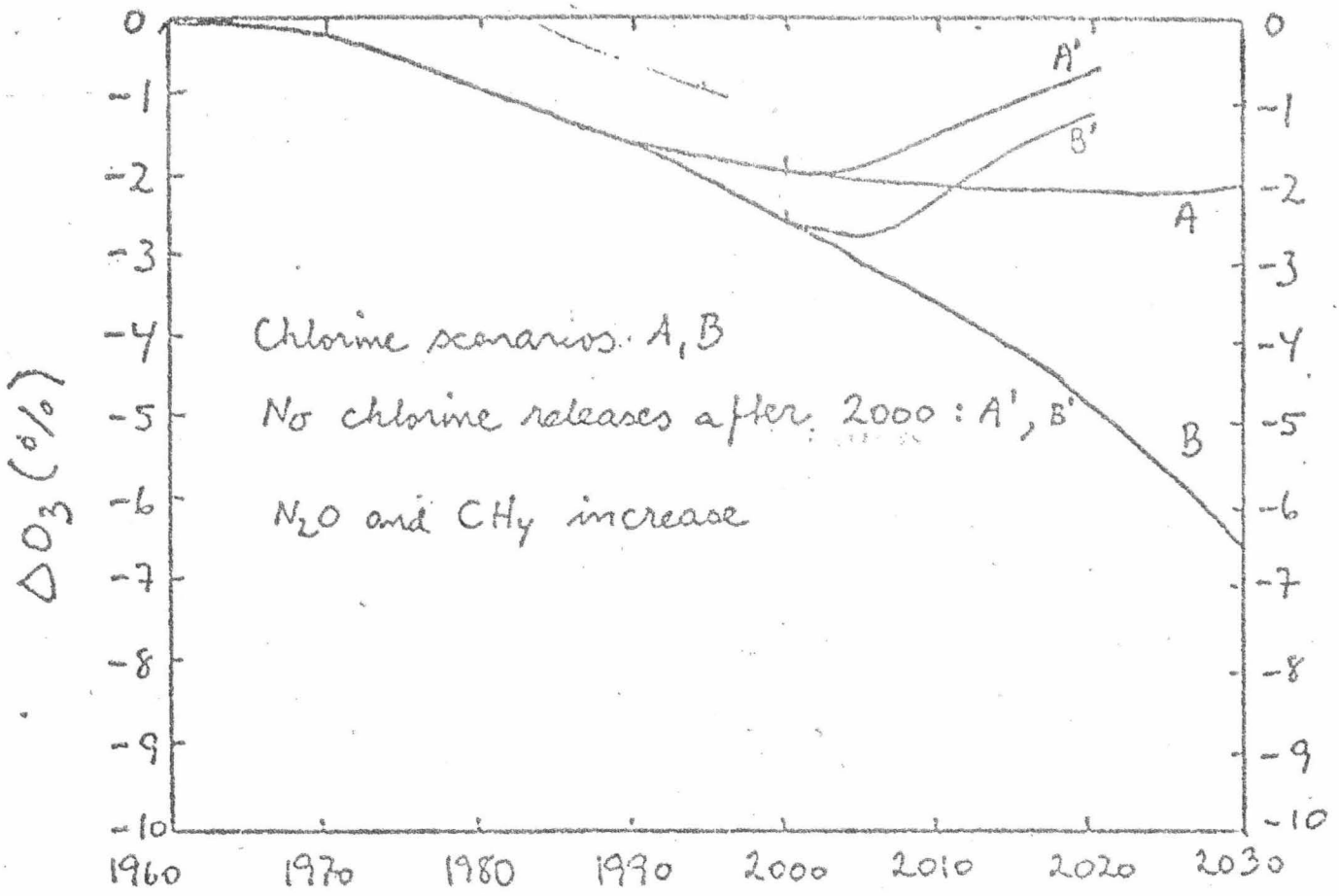


FIGURE 16a

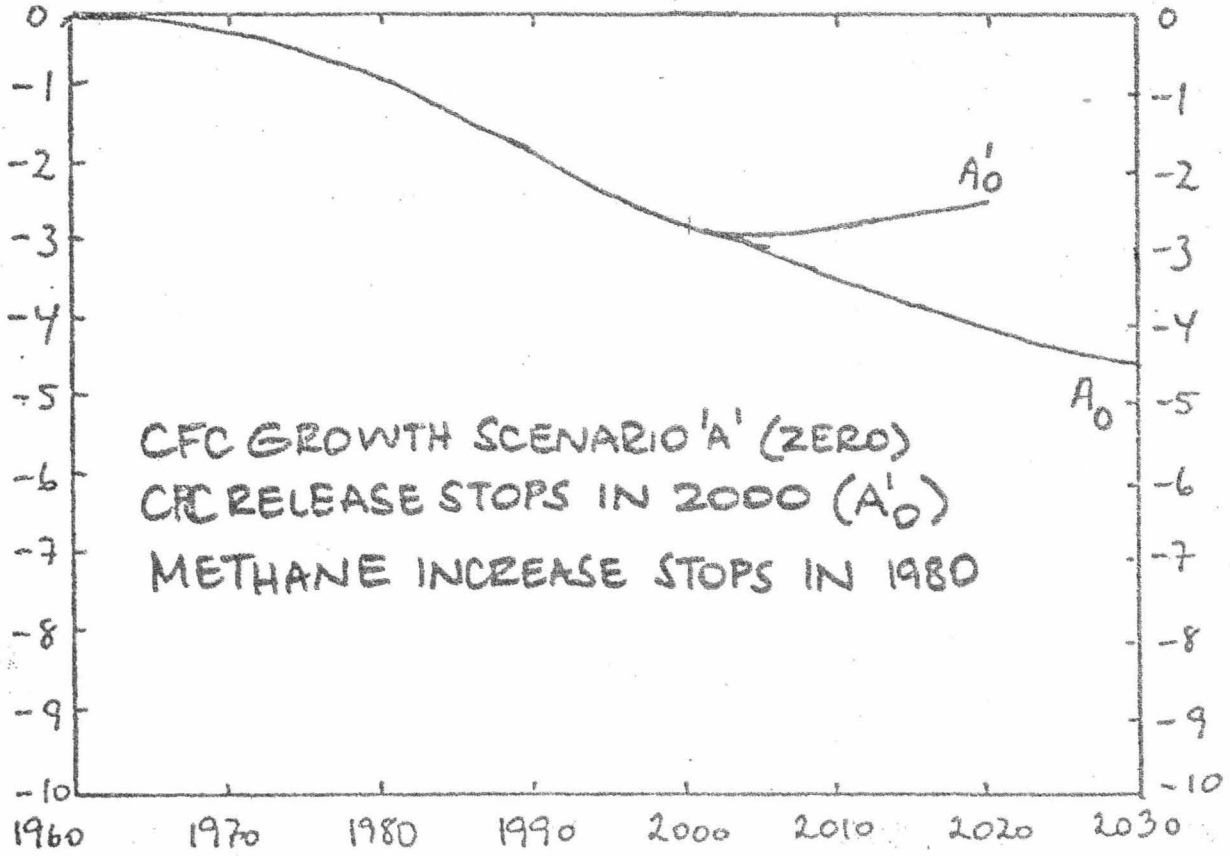
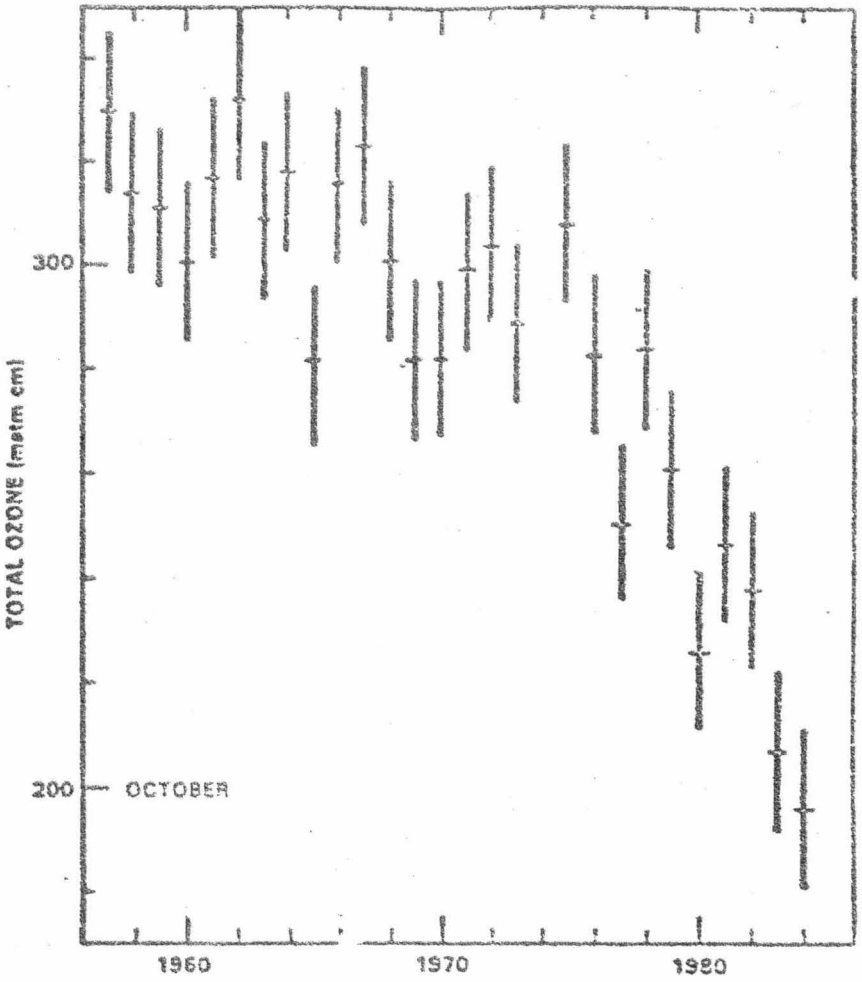
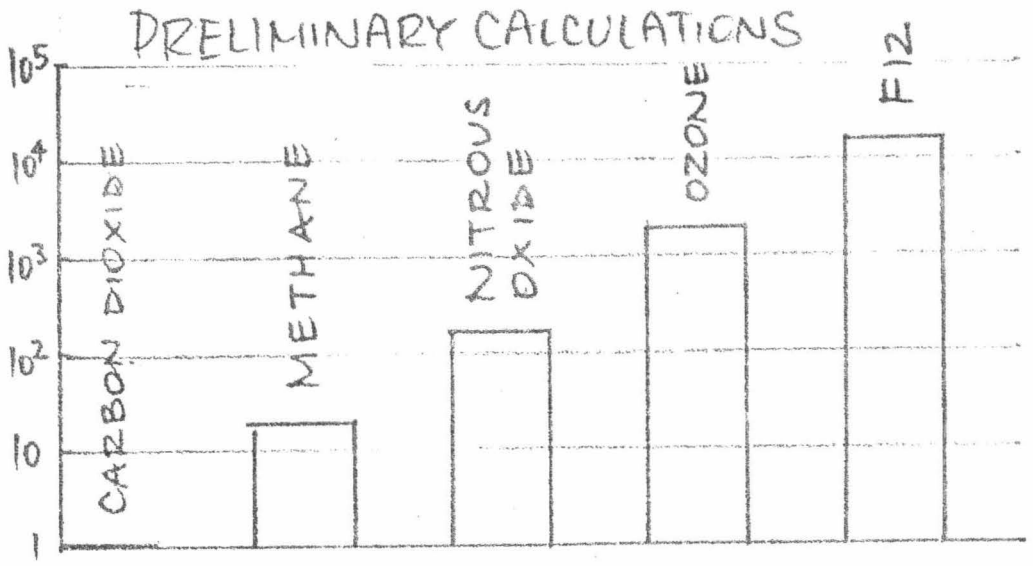


FIGURE 16b



Monthly means of total ozone at Halley Bay for October

FIGURE 17



BOB WATSON WILL GET CORRECT FIGURES FROM HANSON (?

FIGURE 18

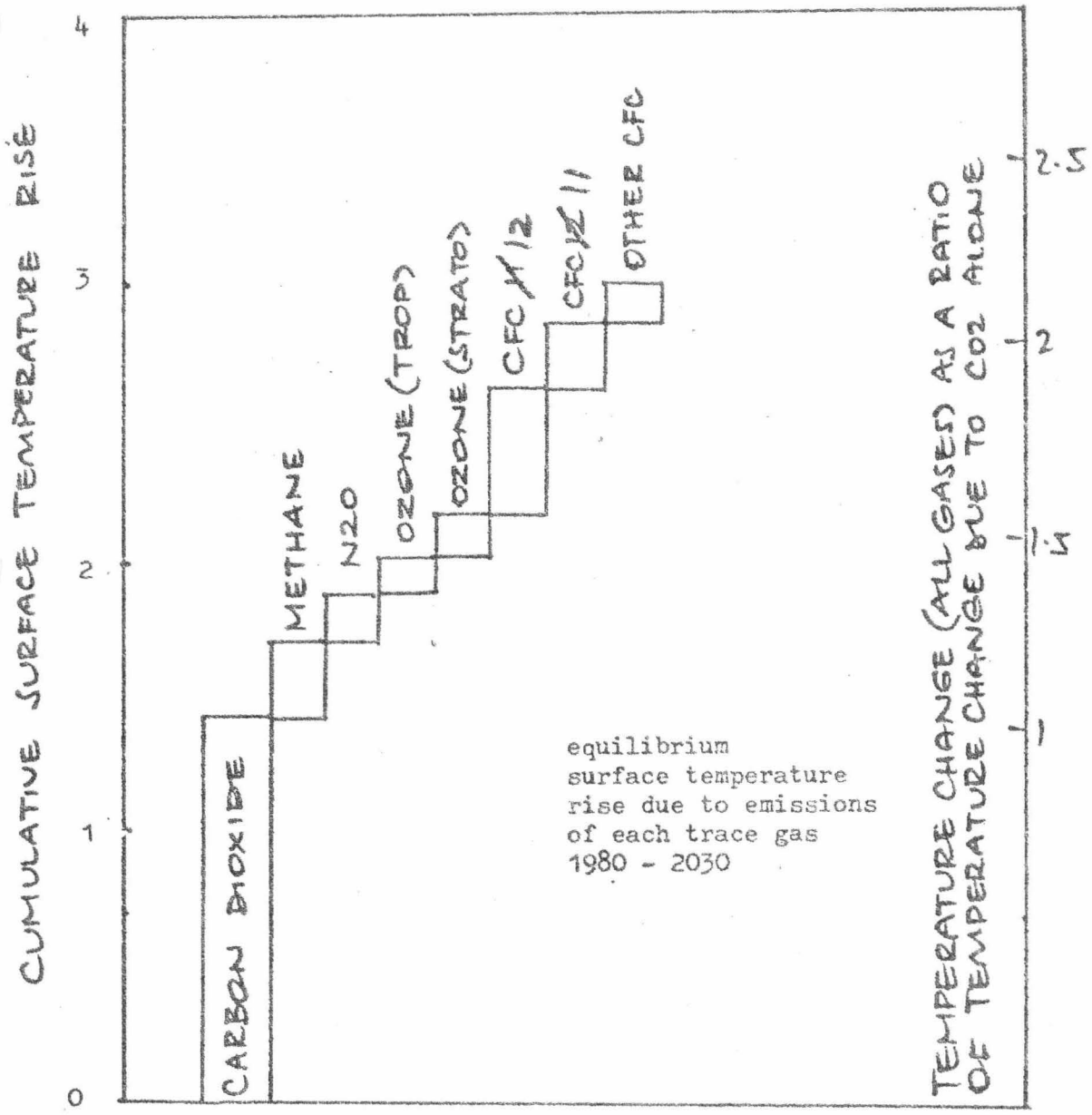
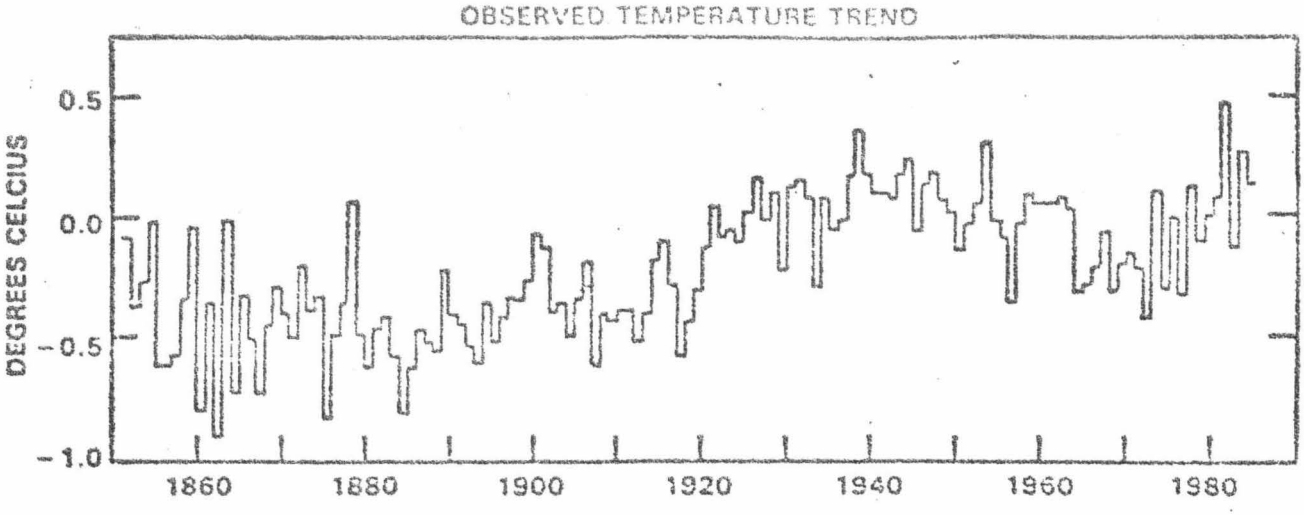


FIGURE 19



Observed surface-air temperature trends for land masses of the Northern Hemisphere.

FIGURE 20