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Ad Hoc Working Group of Legal and Technical
Experts for the preparation of a
Protocol on Chlorofluorocarbons to
the Vienna Convention for the
Protection of the Ozone Layer (Vienna Group)

Third Session
Geneva 27-30 April 1987

AD HOC SCIENTIFIC MEETING TO COMPARE MODEL GENERATED ASSESSMENTS OF OZONE LAYER CHANGE FOR VARIOUS STRATEGIES FOR CFC CONTROL WURZBURG, FEDERAL REPUBLIC OF GERMANY 9-10 APRIL 1987

Na.87-2116

Summary

1. Within the existing limitation of models to accurately simulate the real stratosphere, all models including the fully parameterized model, predicted, within acceptable limits, similar ozone depletions for given CFC control strategies.

2. Under given assumptions for trace gas emissions, stringency of regulations, degree of compliance, and special provisions for developing countries, all regulatory strategies examined will still result in ozone depletion.

3. The amount of ozone depletion depends critically on the control strategy chosen, the substances controlled, the rate of increase in use by developing countries, and other factors. The choice of scenario remains the largest single uncertainty in the model studies examined.

4. From a scientific stand point, a true global freeze of the emissions of CFC 11, CFC 12, CFC 113, and Halons 1211 and 1301 at or below projected 1990 levels is calculated to result in global ozone depletions of less than 2% by 2050. This assumes present growth rates are not significantly changed before 1990.

5. However, even when column ozone depletions are small, or do not occur, a redistribution of ozone in the vertical column is still calculated to occur. This may have consequences for future climate and other adverse impacts.

6. Different substances have different potentials to modify the ozone layer. Regulatory measures limited to CFC 11 and CFC 12 only would still result in significant growth in the chlorine loading of the atmosphere, and hence ozone depletion, given the growth rate of CFC 113 as projected by the USEPA. Also, should there be increasing unregulated use of bromine containing compounds, such as the Halons, which are believed to be especially efficient ozone depleters, then ozone depletion estimates would have to be revised upwards in the future.

7. There are many uncertainties regarding the ability of models to accurately represent the present and future atmosphere. Unexpected and unexplained changes to the atmosphere may occur. Provision may need to be made within the proposed protocol for prompt response to significant ozone changes.

1. PURPOSE OF THE MEETING

Two sessions of the Ad Hoc Working Group of Legal and Technical Experts for the preparation of a Protocol on Chlorofluorocarbons to the Vienna Convention for the Protection of the Ozone Layer (Vienna Group) have been convened by the United Nations Environment Programme during which some progress was made in agreeing the content of a protocol on the control of chlorofluorocarbons. Based on the deliberations of the Vienna Group, its Chairman, Dr. Winfried Lang, prepared a draft of Article II Control Measures and at the request of the meeting, the draft Article was included in a sixth revised draft protocol on the control of chlorofluorocarbons prepared by the UNEP Secretariat.

The Article on Control Measures was included in the draft protocol with the understanding of the meeting that it did not necessarily represent the views of those delegations requesting its inclusion.

The text of the Article is expressed in general terms with several alternative versions of provisions to be included but neither specifying quantitative controls which are yet to be agreed nor the time period in which such limits be applied.

The absence of specific control measures within the article reflect the present state of negotiations among delegations. Several important issues with respect to scope, stringeny and timing have yet to be resolved and include:

1. The list of potential ozone-depleting substances which is to be addressed by the Protocol.

2. The number of years from the entry into force of the Protocol that control measures must be undertaken by the Parties to the Protocol. (It is assumed that 'annual production and imports' or 'adjusted annual production', as defined by the protocol, will be set at the 1986 level or at another similar level.)

3. The number of years after entry into force of the Protocol that a reduction from the 'freeze' levels of the substances to be controlled must be achieved.

4. The extent and rate of future reductions of CFCs under the Protocol.

5. The special conditions or exemptions to be applied to developing countries.

In order that delegations have available to them the best possible information to enable them to understand the ramifications of the different choices, UNEP convened a meeting of scientific experts to review and compare the results of different computer models which simulate the implications for the ozone layer of a standard set of control strategies for CFC control (using USEPA assumptions for CFC growth) and other atmospheric perturbations based on the framework Article II Control Measures referred to above and included as Annex I to this report.

The control options chosen were developed by UNEP in consultation with the Vienna Group Chairman Dr. Lang. Scenarios to illustrate the range of options available were developed for UNEP by the USEPA. It is appreciated that there are many uncertainties associated with projecting the future composition of the atmosphere, not only with respect to the release of substances (i.e. CFCs and Halons) considered for control under the protocol which will be governed by economic and political factors but also relative to the change in concentration of other substances (such as methane, carbon dioxide and nitrous oxide), both naturally occuring and man-made which directly affect the ozone layer or processes which influence atmospheric ozone concentrations. It is emphasized that ozone changes are very sensitive to assumptions made with respect to CFC growth rates for non-compliers (both developed and developing nations).

(Fig. 1) illustrates graphically the effect of the various types of control referred to in the assumptions (viz. yearly compound production increase (e.g. 0%, 2.5%) and rapid decreases due to various control strategies).

It is also understood that assumptions have been made which may eventually prove to be inaccurate. This applies not only to the future composition of trace gases in the atmosphere but also to the degree of compliance by nations with the provisions of the protocol and the time frame within which agreed regulations will be applied.

The limited ability of all models to accurately simulate the reality of a complex atmosphere and the sensitivity of the ozone layer to perturbation must be kept in mind. As has been frequently pointed out, discrepency between the actual behaviour of the atmosphere and its model prediction must limit the confidence to be placed in model results.

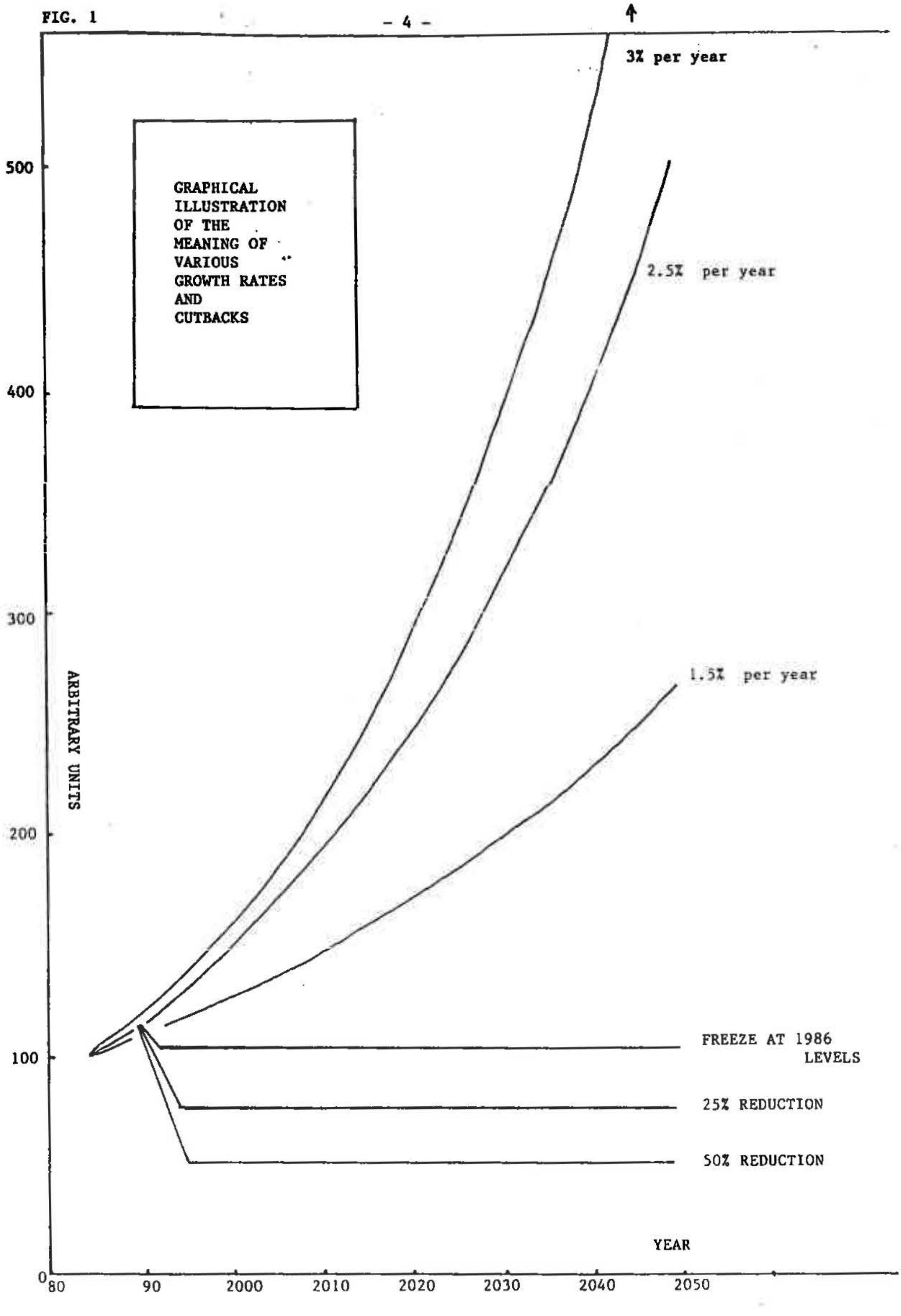
With regard to results obtained using 1-D and 2-D models, the extent to which the various 1-D and 2-D models, developed and run by different groups, show broadly similar depletions (e.g. for CASE 1, the spread at 2050 is from -6.1% to -10.2%, at 2020, -1.7% to -3.3%) may be thought to imply that the results are accurate to this degree (i.e. $\pm \sim 30\%$). However, this is not necessarily the case. The models tend to have similar treatment at atmospheric chemistry and radiation processes. Any significant alteration to the understanding of chemical or dynamic processes, could lead to a change in all these predictions of ozone depletion (in either direction). No model has yet been adequately validated against the real atmosphere (e.g. current ozone distribution) and their reliability for predicting future states of the atmosphere is still uncertain.

Never-the-less based on the framework Article II 'Control Measures' a choice of possible control options has been made and applied simultaneously in a range of European and United States mathematical models and the results compared in an expert group meeting convened by UNEP and participated in by the modellers which carried out the above simulations.

At the Second Session of the Vienna Group, an analysis of the implications of alternative international control strategies for global ozone depletion prepared by the USEPA, was made available to the Group by the United States as a background document. The analysis contained in the paper were derived from a single parametrized model using similar, but not identical, assumptions in the derivation of control strategy scenarios to those used in the scenarios examined in the present exercise.

It was not possible for the Vienna Group to ascertain the reliability of the results presented by the United States in view of the lack of comparison of those results with results from other models examining identical scenarios.

FIG. 1


GRAPHICAL
ILLUSTRATION
OF THE
MEANING OF
VARIOUS
GROWTH RATES
AND
CUTBACKS
3% per year
2.5% per year
1.5% per year
FREEZE AT 1986 LEVELS
25% REDUCTION
50% REDUCTION
ARBITRARY UNITS
YEAR
0
100
200
300
400
500
80
90
2000
2010
2020
2030
2040
2050

The purpose of the present meeting is to correct this deficiency and make available to the Vienna Group:

(i) Assessment of the implications for the atmosphere of a range of CFC control strategies based upon the sixth revised draft Protocol on the control of chlorofluorocarbons, currently under development by the Vienna Group.

(ii) Assessments based on analysis by different models employing identical scenarios.

(iii) Evaluation of the differences, similarities, and reliability of model results through intercomparison by experts.

The above is designed to assist the Vienna Group in making the best choice of control strategy for inclusion in the draft protocol on chlorofluorocarbons.

2. PARTICIPATION IN THE MEETING

The meeting was attended by the following experts: Dr. G. Brasseur (Belgium); Dr. I. Isaksen (Norway); Dr. G. Jenkins (UK); Dr. M. Ko (USA); Dr. D. Sze (USA); Dr. R. Watson (USA); Dr. D. Wuebbles (USA); Mr. P. Usher of the UNEP Secretariat acted as Chairman.

3. CONTROL STRATEGIES AND TRACE GAS EMISSION ESTIMATES SUBJECTED TO MODEL ANALYSIS

Based on the draft of Article II 'Control Strategies', prepared by the Vienna Group Chairman and contained in the sixth revised draft protocol on the control of chlorofluorocarbons emission estimates have been made for ozone depleting substances for the purpose of comparing model estimates of ozone modification. Nine cases of potential future emissions are presented.

Exhibit 1 summarizes the assumptions underlying the nine cases.

Exhibit 2 lists the historical emissions that are commmon to all the cases.

Exhibit 3 presents the trace gas assumptions used (CO_2, CH_4 and N_2O).

Exhibit 4 to 11 present the emissions estimates for the first eight cases.

Assumptions Applied to the Standard Set of Scenarios

In developing scenarios for CFC Control Measures for model intercomparison it was necessary to make several assumptions relating to the future concentrations and rate of accumulation of trace gases in the atmosphere; the degree of compliance by States with the provisions of a protocol; and the possible exemption from control or the application of less stringent controls by developing countries. In all these cases, assumptions were made which may well not represent the real situation of a future world. Possibly, the most questionable of the assumptions made is that relating to future CFC use by developing countries which in all cases has been specified as growing at an overall average of 2.5% per year up to a limit (in some "complying" countries) of 2.5 times current global use per capita (about 0.5 kg per year).

As the model results show, calculated ozone depletion is extremely sensitive to projected developing country use, which, at the specified rate, even under conditions of stringent regulatory obligation for developed countries to freeze and cut back production (cases 7 and 8), still results in significant ozone depletion.

The predicted ozone depletion due to emission scenarios 1 to 8 is composed of contributions from three sources:

(a) Developed countries which comply

(b) Developed countries which do not comply

(c) Developing countries (no compliance or special provisions to allow rapid growth up to 2.5 times per capita use)

Where as group (a) are assumed under some scenarios to be subject to reductions in emissions of 0, 25% or 50%, groups (b) and (c) are allowed unrestrained growth of approximately 2.5% per year although, these are (sometimes very heavily) front end loaded i.e. rapid initial growth followed by later slower growth of under 2.5%.

Whereas the ozone depletion models have not been used in such a way that we can see the contribution to the depletion from groups (a), (b), (c) separately, we can (using the input information from USEPA) show how the <u>emissions</u> of the various compounds are apportioned over the period 1985-2050.

This is shown in Fig. 2 (Case 1). The relative contribution of compliers is also indicated. Also shown is an estimate of emission split 1985-2050 (Developed compliant, Developed non-compliant, Developing) using a different estimate for the 1985 value . This clearly shows the large sensitivity to the initial choice of estimate.

It should be noted that the 2.5% average annual growth rate quoted by USEPA represents an average growth over the period 1990 to 2050. Closer examination of the scenarios reveals that considerably more rapid growth is assumed in this century (for CFC 11 and 12 about 3%, for CFC 22 about 7%, for Halons about 11%) than in the next. In consequence ozone depletion projections remain significant under all strategies for controls applied to developed countries, even for 100% compliance. However, this conclusion is critically dependent on the estimate of the current proportion of CFC which is emitted in developing countries. Nevertheless, even if the assumptions chosen prove to be unrealistic, by application to all scenarios equally it provides an opportunity for the direct comparison of model performance.

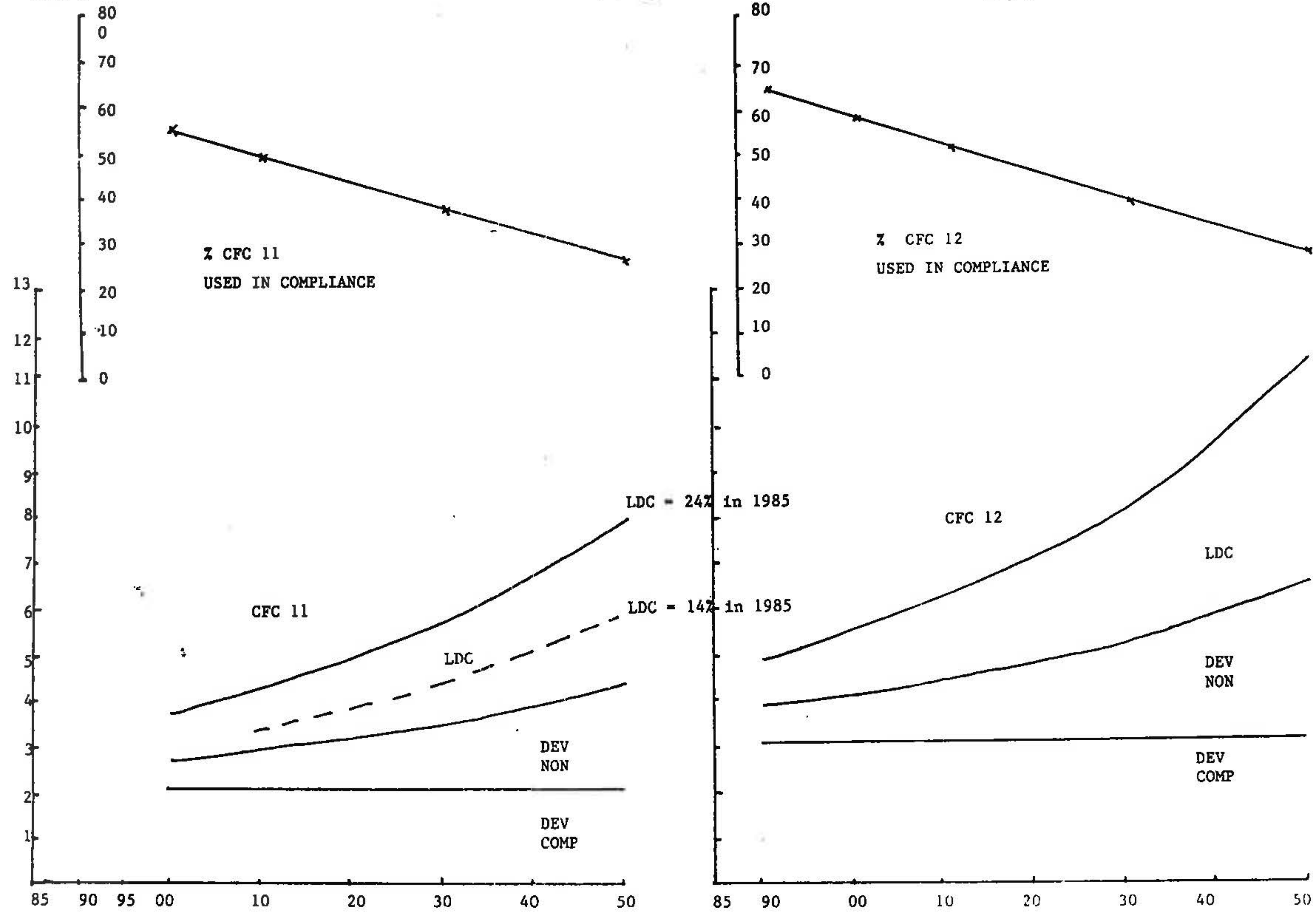
4. METHODS AND MODELS USED FOR PROJECTING THE DEPLETION

Because of the large number of model runs needed to test various permutations of the Chairman's text, it was necessary to utilize a parameterization of a one-dimensional model developed by Peter Connell of Lawrence Livermore National Laboratory as the "work-horse model".

The science panel, however, conducted a careful intercomparison of the results of that model and four other models: that of Dak Sze's of AER, Inc. that of Donald Wuebbles' of Lawrence Livermore National Laboratory; that of Ivar Isaksen's of Oslo University; and that of Guy Brasseur's of the Belgian Institute of Space Aeronomy.

FIG. 2

CASE 1


% CFC 11
USED IN COMPLIANCE
CFC 11
LDC = 24% in 1985
LDC = 14% in 1985
LDC
DEV
NON
DEV
COMP
% CFC 12
USED IN COMPLIANCE
CFC 12
LDC
DEV
NON
DEV
COMP
85
90
95
00
10
20
30
40
50

Assumptions for Case 1: Freeze of CFC-11 and CFC-12, 80% Compliance

- Developed Countries:

  -- Baseline growth from 1985 to 1990
  -- Gradual reduction to 1986 levels from 1990 to 1992
  -- Freeze at 1986 levels from 1992 onward
  -- 80% compliance

- Developing Countries:
  -- Limited at 2.5 times current global use per capita
  -- 20% compliance to limit

- Chemicals covered: CFC-11, CFC-12 (all other chemicals grow at the baseline rate)

- Trace Gases:

  -- CO_2 = NAS 50th percentile
  -- N_2O = 0.2%/yr.
  -- CH_4 = 0.017 ppm/yr.

Assumptions for Case 2: Freeze of CFC-11 and CFC-12, 80% Compliance, Compounded Methane

Same as Case 1 except CH_4 grows at 1%/yr. compounded.

Assumptions for Case 3: Freeze of CFC-11 and CFC-12, 100% Compliance

Same as Case 1 except 100% compliance among developed countries.

Assumptions for Case 4: Freeze of CFC-11, CFC-12, CFC-113, 80% Compliance

Same as Case 1, except CFC-113 is also covered.

Assumptions for Case 5: 25% Reduction of CFC-11, CFC-12, CFC-113, 80% Compliance

- Developed Countries:

  -- Baseline growth from 1985 to 1990
  -- Gradual reduction to 75% of 1986 levels from 1990 to 1994
  -- Freeze at 75% of 1986 levels from 1994 onward
  -- 80% Compliance

- Developing Countries:

  -- Limited at 2.5 times current global use per capita
  -- 40% Compliance to limit

- Chemicals Covered: CFC-11, CFC-12, CFC-113 (all other chemicals grow at baseline rate)

- Trace Gases:

  -- CO2 = NAS 50th percentile
  -- N2O = 0.2%/yr.
  -- CH4 = 0.017 ppm/yr.

Assumptions for Case 6: 50% Reduction of Fully-Halogenated Compounds, 80% Compliance

- Developed Countries:

  -- Baseline growth from 1985 to 1990
  -- Gradual reduction to 50% of 1986 levels from 1990 to 1996
  -- Freeze at 50% of 1986 levels from 1996 onward
  -- 80% Compliance

- Developing Countries:

  -- Limited at 2.5 times current global use per capita
  -- 40% Compliance to limit

- Chemicals Covered: All fully-halogenated compounds (CFC-11, CFC-12, CFC-113, Halon 1211, Halon 1301), other chemicals grow at baseline rate

- Trace Gases:

  -- CO2 = NAS 50th percentile
  -- N2O = 0.2%/yr.
  -- CH4 = 0.017 ppm/yr.

Assumptions for Case 7: 50% Reduction of Fully-Halogenated Compounds, 80% Compliance, Compounded Methane

Same as Case 6, except CH4 grows at 1%/yr. compounded

Assumptions for Case 8: 50% Reduction of Fully-Halogenated Compounds, 100% Compliance

Same as Case 6, except 100% compliance among developed countries.

Assumptions for Case 9: A complete worldwide freeze of emissions of all halocarbons starting in 1990.

Chemicals covered: CFC-11, CFC-12, CFC-113, CFC-22, CCl_4, CH_3CCl_3, Halon 1211, Halon 1301.

Trace Gases:

-- CO_2 = NAS 50th percentile
-- N2O = 0.2%/yr.
-- CH4 = 0.017 ppm/yr.

EXHIBIT 1

ASSUMPTIONS

Assumptions Common to All Cases:

- Baseline Use: In the absence of controls, use grows at an average annual rate of 2.5 percent from 1985 to 2050, with no growth thereafter. However, this overall average rate consists of higher annual rates in early years (e.g. 11.6% for the Halons from 1985-1990) followed by less than 2.5% annual rate in later years.

- Baseline Emissions: Emissions are estimated based on historical and simulated future use and the expected lags in emissions associated with certain applications (e.g., refrigeration). Note that emissions are not specified directly, but are derived from use.

- Controls: Controls are applied to use; reductions in emissions may lag the reduction in use due to emissions of historical production from existing products (note that for applications other than Halon fire extinguishing systems and rigid PU foam, this lag is reasonably small, less than 10 years).

- Compliance: Compliance less than 100 percent (e.g., 80 percent) is represented as follows:

  A. The baseline is divided into two parts (compliance and non-compliance) using the compliance rate (e.g., 80 percent).

  B. The compliance portion of the baseline follows the prescribed policy (e.g., 80 percent of the baseline remains fixed at the 1986 level in the case of a freeze at 1986 levels).

  C. The non-compliance portion of the baseline grows at the baseline rate (e.g., 20 percent of the baseline grows at 2.5 percent per year through 2050).

  D. The resulting production over time is the sum of the two portions of the baseline (compliance and non-compliance).

  Developing countries: The use in developing countries is allowed to grow under all the cases examined. The limit to growth examined is 0.5 kg/person for CFC-11 and CFC-12. This value is approximately 2.5 times the current global average use per capita for these chemicals. For cases where other chemicals are controlled as well, developing nations are permitted to grow to 2.5 times the current global average use per capita for each of the additional chemicals.

  The proportion of use in the developed countries for 1985 estimated by USEPA to be as follows:

CFC 11	76%	)
CFC 12	78%	)
CFC 22	92%	) These proportions are uncertain, and have been
CFC 113	83%	) questioned. They have a dominating influence
CCl_4	78%	) on the ozone depletion calculated, because of
$CH_3 CCl_3$	85%	) the large compounding increase which the
Halon 1211	77%	) developing countries use undergoes.
Halon 1301	85%	)

EXHIBIT 2

HISTORICAL EMISSIONS COMMON TO ALL CASES

ANNUAL GLOBAL EMISSIONS (MILL KG)

YEAR	CFC11	CFC12	CFC22	CFC113	CCL4	CH3CCL3	HALON 1211	HALON 1301
1935	0.0	0.3	0.0	0.0	49.7	0.0	0.0	0.0
1940	0.1	2.1	0.0	0.0	84.7	0.0	0.0	0.0
1945	0.4	7.1	0.0	0.0	116.8	0.0	0.0	0.0
1950	5.6	28.8	0.1	0.0	108.8	0.0	0.0	0.0
1955	21.5	46.9	0.6	0.0	91.0	3.4	0.0	0.0
1960	38.2	88.5	2.6	2.5	84.8	27.8	0.0	0.0
1965	100.8	167.6	7.3	6.5	97.0	65.9	0.0	0.0
1970	191.2	300.5	18.3	17.0	121.4	156.6	0.0	0.0
1975	323.5	434.6	46.0	44.3	131.2	371.9	0.0	0.0
1980	264.5	388.6	71.9	97.3	131.2	454.5	0.0	0.0
1985	298.0	438.0	81.2	138.5	71.2	499.5	2.6	2.6

EXHIBIT 3

TRACE GAS ASSUMPTIONS

	CO2 (ppm)	N2O (ppm)	CH4 LINEAR (ppm)	CH4 COMPOUNDED (ppm)
1985	350.2	303.1	1.756	1.756
1990	355.5	306.1	1.841	1.846
1995	360.7	309.2	1.926	1.940
2000	366.0	312.3	2.011	2.039
2005	377.2	315.5	2.096	2.143
2010	388.4	318.6	2.181	2.252
2015	399.6	321.8	2.266	2.367
2020	410.8	325.1	2.351	2.488
2025	422.0	328.3	2.436	2.614
2030	439.2	331.6	2.521	2.748
2035	456.4	334.9	2.606	2.888
2040	473.6	338.3	2.691	3.035
2045	490.8	341.7	2.776	3.190
2050	508.0	345.1	2.861	3.353
2055	531.4	348.6	2.946	3.524
2060	554.8	352.1	3.031	3.704
2065	578.2	355.6	3.116	3.893
2070	601.6	359.2	3.201	4.091
2075	625.0	362.8	3.286	4.300
2080	654.4	366.5	3.371	4.519
2085	683.8	370.1	3.456	4.750
2090	713.2	373.8	3.541	4.992
2095	742.6	377.6	3.626	5.247
2100	772.0	381.4	3.711	5.514

CO2 = NAS 50th Percentile
N2O = 0.2% per year
CH4 linear = 0.017 ppm per year
CH4 compounded = 1% per year

EXHIBIT 4

CASE 1 EMISSIONS

YEAR	CFC-11	CFC-12	CFC-22	CFC-113	CCL4	CH3CCL3	HALON 1211	HALON 1301
-----	-----	-----	-----	-----	-----	-----	-----	-----
1990	343.6	504.5	117.6	166.5	80.5	564.8	4.5	4.5
1995	381.9	530.8	133.1	200.2	91.1	638.3	6.7	6.7
2000	420.4	566.1	150.6	240.5	103.0	720.8	9.3	9.3
2005	460.4	604.8	170.3	272.2	116.5	811.4	11.9	11.8
2010	495.7	648.2	192.7	308.0	131.9	913.4	14.7	14.4
2015	536.0	697.7	217.9	348.5	149.2	1028.3	17.8	17.1
2020	580.3	734.4	246.4	394.4	168.9	1157.5	21.1	19.9
2025	629.1	817.6	278.7	446.3	191.1	1303.1	25.4	22.7
2030	684.0	888.4	315.2	505.0	216.2	1466.9	29.0	25.3
2035	746.4	969.4	356.5	571.4	244.7	1651.3	33.1	28.1
2040	817.3	1061.9	403.3	646.6	276.9	1858.9	37.6	31.1
2045	898.1	1167.8	456.1	731.7	313.3	2092.6	42.5	34.4
2050	990.4	1288.8	515.8	827.9	354.6	2355.7	48.1	37.9
2055	1037.3	1319.5	552.0	827.9	354.6	2355.7	52.1	40.4
2060	1070.5	1321.2	552.0	827.9	354.6	2355.7	55.6	42.5
2065	1091.2	1322.2	552.0	827.9	354.6	2355.7	58.6	44.2
2070	1097.5	1322.5	552.0	827.9	354.6	2355.7	61.1	45.6
2075	1097.5	1322.5	552.0	827.9	354.6	2355.7	63.1	46.7
2080	1097.5	1322.5	552.0	827.9	354.6	2355.7	64.8	47.4
2085	1097.5	1322.5	552.0	827.9	354.6	2355.7	66.0	47.8
2090	1097.5	1322.5	552.0	827.9	354.6	2355.7	66.7	48.0
2095	1097.5	1322.5	552.0	827.9	354.6	2355.7	66.7	48.0
2100	1097.5	1322.5	552.0	827.9	354.6	2355.7	66.7	48.0

All values in millions of kilograms

EXHIBIT 5

CASE 2 EMISSIONS

YEAR	CFC-11	CFC-12	CFC-22	CFC-113	CCL4	CH3CCL3	HALON 1211	HALON 1301
-----	-----	-----	-----	-----	-----	-----	-----	-----
1990	343.4	504.5	117.6	166.5	80.5	564.8	4.5	4.5
1995	381.9	530.8	133.1	200.2	91.1	638.3	6.7	6.7
2000	420.4	566.1	150.6	240.5	103.0	720.8	9.3	9.3
2005	460.4	604.8	170.3	272.2	116.5	811.4	11.9	11.8
2010	495.7	648.2	192.7	308.0	131.9	913.4	14.7	14.4
2015	536.0	697.7	217.9	348.5	149.2	1028.3	17.8	17.1
2020	580.3	754.4	246.4	394.4	168.9	1157.5	21.1	19.9
2025	629.1	817.6	278.7	446.3	191.1	1303.1	25.4	22.7
2030	684.0	888.4	315.2	505.0	216.2	1466.9	29.0	25.3
2035	746.4	969.4	356.5	571.4	244.7	1651.3	33.1	28.1
2040	817.3	1061.9	403.3	646.6	276.9	1858.9	37.6	31.1
2045	898.1	1167.8	456.1	731.7	313.3	2092.6	42.5	34.4
2050	990.4	1288.8	515.8	827.9	354.6	2355.7	48.1	37.9
2055	1037.3	1319.5	552.0	827.9	354.6	2355.7	52.1	40.4
2060	1070.5	1321.2	552.0	827.9	354.6	2355.7	55.6	42.5
2065	1091.2	1322.2	552.0	827.9	354.6	2355.7	58.6	44.2
2070	1097.5	1322.5	552.0	827.9	354.6	2355.7	61.1	45.6
2075	1097.5	1322.5	552.0	827.9	354.6	2355.7	63.1	46.7
2080	1097.5	1322.5	552.0	827.9	354.6	2355.7	64.8	47.4
2085	1097.5	1322.5	552.0	827.9	354.6	2355.7	66.0	47.8
2090	1097.5	1322.5	552.0	827.9	354.6	2355.7	66.7	48.0
2095	1097.5	1322.5	552.0	827.9	354.6	2355.7	66.7	48.0
2100	1097.5	1322.5	552.0	827.9	354.6	2355.7	66.7	48.0

EXHIBIT 6

CASE 3 EMISSIONS

YEAR	CFC-11	CFC-12	CFC-22	CFC-113	CCL4	CH3CCL3	HALON 1211	HALON 1301
-----	-----	-----	-----	-----	-----	-----	-----	-----
1990	341.9	500.4	117.6	166.5	80.5	564.8	4.5	4.5
1995	376.6	516.0	133.1	200.2	91.1	638.3	6.7	6.7
2000	410.0	540.6	150.6	240.5	103.0	720.8	9.3	9.3
2005	441.0	567.3	170.3	272.2	116.5	811.4	11.9	11.8
2010	465.7	596.9	192.7	308.0	131.9	913.4	14.7	14.4
2015	494.9	631.0	217.9	348.5	149.2	1028.3	17.8	17.1
2020	527.4	670.5	246.4	394.4	168.9	1157.5	21.1	19.9
2025	563.2	714.5	278.7	446.3	191.1	1303.1	25.4	22.7
2030	603.7	763.7	315.2	505.0	216.2	1466.9	29.0	25.3
2035	649.9	820.5	356.5	571.4	244.7	1651.3	33.1	28.1
2040	702.9	886.0	403.3	646.6	276.9	1858.9	37.6	31.1
2045	763.6	961.6	456.1	731.7	313.3	2092.6	42.5	34.4
2050	833.5	1048.8	515.8	827.9	354.6	2355.7	48.1	37.9
2055	868.8	1071.0	552.0	827.9	354.6	2355.7	52.1	40.4
2060	893.9	1072.2	552.0	827.9	354.6	2355.7	55.6	42.5
2065	909.6	1073.0	552.0	827.9	354.6	2355.7	58.6	44.2
2070	914.4	1073.1	552.0	827.9	354.6	2355.7	61.1	45.6
2075	914.4	1073.1	552.0	827.9	354.6	2355.7	63.1	46.7
2080	914.4	1073.1	552.0	827.9	354.6	2355.7	64.8	47.4
2085	914.4	1073.1	552.0	827.9	354.6	2355.7	66.0	47.8
2090	914.4	1073.1	552.0	827.9	354.6	2355.7	66.7	48.0
2095	914.4	1073.1	552.0	827.9	354.6	2355.7	66.7	48.0
2100	914.4	1073.1	552.0	827.9	354.6	2355.7	66.7	48.0

All values in millions of kilograms

EXHIBIT 7

CASE 4 EMISSIONS

YEAR	CFC-11	CFC-12	CFC-22	CFC-113	CCL4	CH3CCL3	HALON 1211	HALON 1301
1990	343.4	504.5	117.6	152.2	80.5	564.8	4.5	4.5
1995	381.9	530.8	133.1	164.9	91.1	638.3	6.7	6.7
2000	420.4	566.1	150.6	180.4	103.0	720.8	9.3	9.3
2005	460.4	604.9	170.3	192.8	116.5	811.4	11.9	11.8
2010	495.8	648.2	192.7	206.7	131.9	913.4	14.7	14.4
2015	536.0	697.7	217.9	222.6	149.2	1028.3	17.8	17.1
2020	580.3	754.4	246.4	240.9	168.9	1157.5	21.1	19.9
2025	629.3	818.0	278.7	261.2	191.1	1303.1	25.4	22.7
2030	684.3	888.8	315.2	284.0	216.2	1466.9	29.0	25.3
2035	746.7	969.8	356.5	310.1	244.7	1651.3	33.1	28.1
2040	817.7	1062.3	403.3	339.9	276.9	1858.9	37.6	31.1
2045	898.5	1168.2	456.1	374.0	313.3	2092.6	42.5	34.4
2050	990.7	1289.2	515.8	412.9	354.6	2355.7	48.1	37.9
2055	1037.7	1319.9	552.0	412.9	354.6	2355.7	52.1	40.4
2060	1070.8	1321.6	552.0	412.9	354.6	2355.7	55.6	42.5
2065	1091.6	1322.6	552.0	412.9	354.6	2355.7	58.6	44.2
2070	1097.9	1322.9	552.0	412.9	354.6	2355.7	61.1	45.6
2075	1097.9	1322.9	552.0	412.9	354.6	2355.7	63.1	46.7
2080	1097.9	1322.9	552.0	412.9	354.6	2355.7	64.8	47.4
2085	1097.9	1322.9	552.0	412.9	354.6	2355.7	66.0	47.8
2090	1097.9	1322.9	552.0	412.9	354.6	2355.7	66.7	48.0
2095	1097.9	1322.9	552.0	412.9	354.6	2355.7	66.7	48.0
2100	1097.9	1322.9	552.0	412.9	354.6	2355.7	66.7	48.0

All values in millions of kilograms

EXHIBIT 8

CASE 5 EMISSIONS

YEAR	CFC-11	CFC-12	CFC-22	CFC-113	CCL4	CH3CCL3	HALON 1211	HALON 1301
-----	-----	-----	-----	-----	-----	-----	-----	-----
1990	343.4	504.5	117.6	152.2	80.5	564.8	4.5	4.5
1995	341.8	465.6	133.1	141.0	91.1	638.3	6.7	6.7
2000	374.1	490.3	150.6	156.5	103.0	720.8	9.3	9.3
2005	408.8	528.7	170.3	168.9	116.5	811.4	11.9	11.8
2010	438.5	570.9	192.7	182.5	131.9	913.4	14.7	14.4
2015	476.5	619.3	217.9	198.2	149.2	1028.3	17.8	17.1
2020	519.9	674.7	246.4	216.0	168.9	1157.5	21.1	19.9
2025	566.9	735.5	278.7	235.4	191.1	1303.1	25.4	22.7
2030	618.5	801.1	315.2	256.7	216.2	1466.9	29.0	25.3
2035	676.6	876.0	356.5	281.0	244.7	1651.3	33.1	28.1
2040	742.2	961.5	403.3	308.8	276.9	1858.9	37.6	31.1
2045	816.5	1059.1	456.1	340.5	313.3	2092.6	42.5	34.4
2050	901.2	1170.6	515.8	376.7	354.6	2355.7	48.1	37.9
2055	944.4	1198.9	552.0	376.7	354.6	2355.7	52.1	40.4
2060	974.8	1200.5	552.0	376.7	354.6	2355.7	55.6	42.5
2065	993.9	1201.4	552.0	376.7	354.6	2355.7	58.6	44.2
2070	999.6	1201.7	552.0	376.7	354.6	2355.7	61.1	45.6
2075	999.6	1201.7	552.0	376.7	354.6	2355.7	63.1	46.7
2080	999.6	1201.7	552.0	376.7	354.6	2355.7	64.8	47.4
2085	999.6	1201.7	552.0	376.7	354.6	2355.7	66.0	47.8
2090	999.6	1201.7	552.0	376.7	354.6	2355.7	66.7	48.0
2095	999.6	1201.7	552.0	376.7	354.6	2355.7	66.7	48.0
2100	999.6	1201.7	552.0	376.7	354.6	2355.7	66.7	48.0

All values in millions of kilograms

EXHIBIT 9

CASE 6 EMISSIONS

YEAR	CFC-11	CFC-12	CFC-22	CFC-113	CCL4	CH3CCL3	HALON 1211	HALON 1301
-----	-----	-----	-----	-----	-----	-----	-----	-----
1990	343.4	504.5	117.6	152.2	80.5	564.8	4.3	4.3
1995	316.5	428.0	133.1	125.1	91.1	638.3	5.2	5.0
2000	329.9	414.8	150.6	132.6	103.0	720.8	6.4	6.0
2005	359.5	452.9	170.3	145.0	116.5	811.4	7.7	7.1
2010	384.1	494.8	192.7	158.7	131.9	913.4	9.1	8.3
2015	418.4	543.0	217.9	174.4	149.2	1028.3	10.6	9.4
2020	461.9	598.4	246.4	192.2	168.9	1157.5	12.3	10.7
2025	509.2	659.8	278.7	211.8	191.1	1303.1	14.7	11.7
2030	560.9	725.6	315.2	233.1	216.2	1466.9	16.0	12.4
2035	619.2	800.5	356.5	257.4	244.7	1651.3	17.4	13.3
2040	684.9	886.0	403.3	285.2	276.9	1858.9	19.4	14.3
2045	759.2	983.6	456.1	316.9	313.3	2092.6	21.5	15.5
2050	843.9	1095.1	515.8	353.1	354.6	2355.7	23.9	16.8
2055	887.1	1123.4	552.0	353.1	354.6	2355.7	25.7	17.7
2060	917.5	1125.0	552.0	353.1	354.6	2355.7	27.2	18.5
2065	936.6	1126.0	552.0	353.1	354.6	2355.7	28.5	19.1
2070	942.3	1126.2	552.0	353.1	354.6	2355.7	29.5	19.6
2075	942.3	1126.2	552.0	353.1	354.6	2355.7	30.4	20.0
2080	942.3	1126.2	552.0	353.1	354.6	2355.7	31.1	20.2
2085	942.3	1126.2	552.0	353.1	354.6	2355.7	31.7	20.4
2090	942.3	1126.2	552.0	353.1	354.6	2355.7	32.0	20.4
2095	942.3	1126.2	552.0	353.1	354.6	2355.7	32.0	20.4
2100	942.3	1126.2	552.0	353.1	354.6	2355.7	32.0	20.4

All values in millions of kilograms

EXHIBIT 10

CASE 7 EMISSIONS

YEAR	CFC-11	CFC-12	CFC-22	CFC-113	CCL4	CH3CCL3	HALON 1211	HALON 1301
-----	-----	-----	-----	-----	-----	-----	-----	-----
1990	343.4	504.5	117.6	152.2	80.5	564.8	4.3	4.3
1995	316.5	428.0	133.1	125.1	91.1	638.3	5.2	5.0
2000	329.9	414.8	150.6	132.6	103.0	720.8	6.4	6.0
2005	359.5	452.9	170.3	145.0	116.5	811.4	7.7	7.1
2010	384.1	494.8	192.7	158.7	131.9	913.4	9.1	8.3
2015	418.4	543.0	217.9	174.4	149.2	1028.3	10.6	9.4
2020	461.9	598.4	246.4	192.2	168.9	1157.5	12.3	10.7
2025	509.2	659.8	278.7	211.8	191.1	1303.1	14.7	11.7
2030	560.9	725.6	315.2	233.1	216.2	1466.9	16.0	12.4
2035	619.2	800.5	356.5	257.4	244.7	1651.3	17.4	13.3
2040	684.9	886.0	403.3	285.2	276.9	1858.9	19.4	14.3
2045	759.2	983.6	456.1	316.9	313.3	2092.6	21.5	15.5
2050	843.9	1095.1	515.8	353.1	354.6	2355.7	23.9	16.8
2055	887.1	1123.4	552.0	353.1	354.6	2355.7	25.7	17.7
2060	917.5	1125.0	552.0	353.1	354.6	2355.7	27.2	18.5
2065	936.6	1126.0	552.0	353.1	354.6	2355.7	28.5	19.1
2070	942.3	1126.2	552.0	353.1	354.6	2355.7	29.5	19.6
2075	942.3	1126.2	552.0	353.1	354.6	2355.7	30.4	20.0
2080	942.3	1126.2	552.0	353.1	354.6	2355.7	31.1	20.2
2085	942.3	1126.2	552.0	353.1	354.6	2355.7	31.7	20.4
2090	942.3	1126.2	552.0	353.1	354.6	2355.7	32.0	20.4
2095	942.3	1126.2	552.0	353.1	354.6	2355.7	32.0	20.4
2100	942.3	1126.2	552.0	353.1	354.6	2355.7	32.0	20.4

All values in millions of kilograms

EXHIBIT 11

CASE 8 EMISSIONS

YEAR	CFC-11	CFC-12	CFC-22	CFC-113	CCL4	CH3CCL3	HALON 1211	HALON 1301
-----	-----	-----	-----	-----	-----	-----	-----	-----
1990	341.9	500.4	117.6	148.6	80.5	564.8	4.2	4.2
1995	294.8	387.5	133.1	106.3	91.1	638.3	4.8	4.5
2000	296.9	351.5	150.6	105.6	103.0	720.8	5.7	5.2
2005	314.9	377.4	170.3	113.2	116.5	811.4	6.7	6.0
2010	326.2	405.4	192.7	121.5	131.9	913.4	7.7	6.8
2015	348.3	438.1	217.9	131.1	149.2	1028.3	8.9	7.5
2020	379.9	476.2	246.4	142.1	168.9	1157.5	10.1	8.4
2025	414.3	518.4	278.7	154.0	191.1	1303.1	12.0	8.9
2030	451.5	562.6	315.2	166.8	216.2	1466.9	12.8	9.2
2035	493.6	613.3	356.5	181.5	244.7	1651.3	13.4	9.6
2040	541.3	671.8	403.3	198.4	276.9	1858.9	15.0	10.2
2045	595.5	739.2	456.1	218.0	313.3	2092.6	16.5	10.9
2050	657.8	816.9	515.8	240.5	354.6	2355.7	18.2	11.7
2055	689.4	836.6	552.0	240.5	354.6	2355.7	19.5	12.2
2060	711.8	837.7	552.0	240.5	354.6	2355.7	20.5	12.7
2065	725.8	838.4	552.0	240.5	354.6	2355.7	21.5	13.0
2070	730.1	838.6	552.0	240.5	354.6	2355.7	22.2	13.3
2075	730.1	838.6	552.0	240.5	354.6	2355.7	22.9	13.6
2080	730.1	838.6	552.0	240.5	354.6	2355.7	23.4	13.7
2085	730.1	838.6	552.0	240.5	354.6	2355.7	23.8	13.8
2090	730.1	838.6	552.0	240.5	354.6	2355.7	24.0	13.8
2095	730.1	838.6	552.0	240.5	354.6	2355.7	24.0	13.8
2100	730.1	838.6	552.0	240.5	354.6	2355.7	24.0	13.8

All values in millions of kilograms

5. RESULTS

The response of the model calculated column abundance of O_3 to the nine emission scenarios is illustrated in figure 3. Case 9 represents the case where all emissions are frozen at 1990 level. The remainder can be divided into two groups representing control on F-11, F-12 and F-113 (Cases 1-5) in one group and a second group providing additional control on H-1211 and H-1301 (Cases 6-8).

The calculated response of O_3 is consistent with the amount of total chlorine (ranging from 16 ppbv in Cases 1 to 8 ppbv in Case 9) and total bromine (ranging from 70 pptv in Cases 1 to 15 pptv in Case 9) in the models. It should be noted that the effect of bromine is mainly through the interaction of BrO with ClO making the O_3-removal efficiency of bromine on a per molecule basis much higher at elevated chlorine background levles.

Comparison of Cases 1 with 2 and Cases 6 with 7 illustrates that the effect of different CH_4growth rate (1% per year compound vs 17 ppb per year) is relatively small: about 0.5% in O_3 change in the AER and Guy Brasseur model; up to 1% difference in the LLNL and Oslo model by the year 2050.

The calculations of ozone depletion from 5 different models were compared for 4 of the emision scenarios (Fig. 4). Three of these models (LLNL, AER, GB) are conventional 1-D models, one is a highly parameterized model (Connell, 1986) based on the LLNL 1-D model, and one is a 2D diabetic circulation model (Isaksen Oslo model). Estimated increase in the chlorine content of the stratosphere over the tune period of 70 years, differs by less than 10% in the five models, for each of the scenarios. Except for the GB 1-D model and the 2D model, bromine chemistry is included in the calculations. Bromine chemistry becomes significant for ozone depletion towards the end of the predicted period, due to the assumed fast growth in bromine compounds, making a comparison between studies with, and without, bromine chemistry less certain.

For the time period assigned in the comparions, 1985-2050, the estimated depletions agree within a factor of two. The largest global average depletion is obtained by the 2-D model, while the parameterized model provides somewhat less ozone depletion than the 1-D models in all comparisons made.

It should be mentioned here that the results are quite sensitive to the bromine scenario, while the parameterized model has not been extensively verified against the conventional 1D model for bromine perturbations.

Within the range of cases run, the results are consistent.

6. Relative Ozone Depletion Potential

Although all Halocarbons are contributors to stratospheric chlorine and/or bromine, its individual effect (on per unit mass basis) on ozone varies greatly according to the number of Br and Cl atoms it contains, its atmospheric life times and molecular weight and its vertical distribution in the stratosphere. Table 1 summarizes the calculated ozone depletion potential (ODP) relative to CFC-11 for various halocarbons including H 1301 and H 1211. Those halocarbons that contain H-atoms (e.g. CFC-22, methyl chloroform and methylene chloride) are calculated to have small ODP values while its ODP for the fully halogenated halocarbons are around unity or larger.

FIG. 3

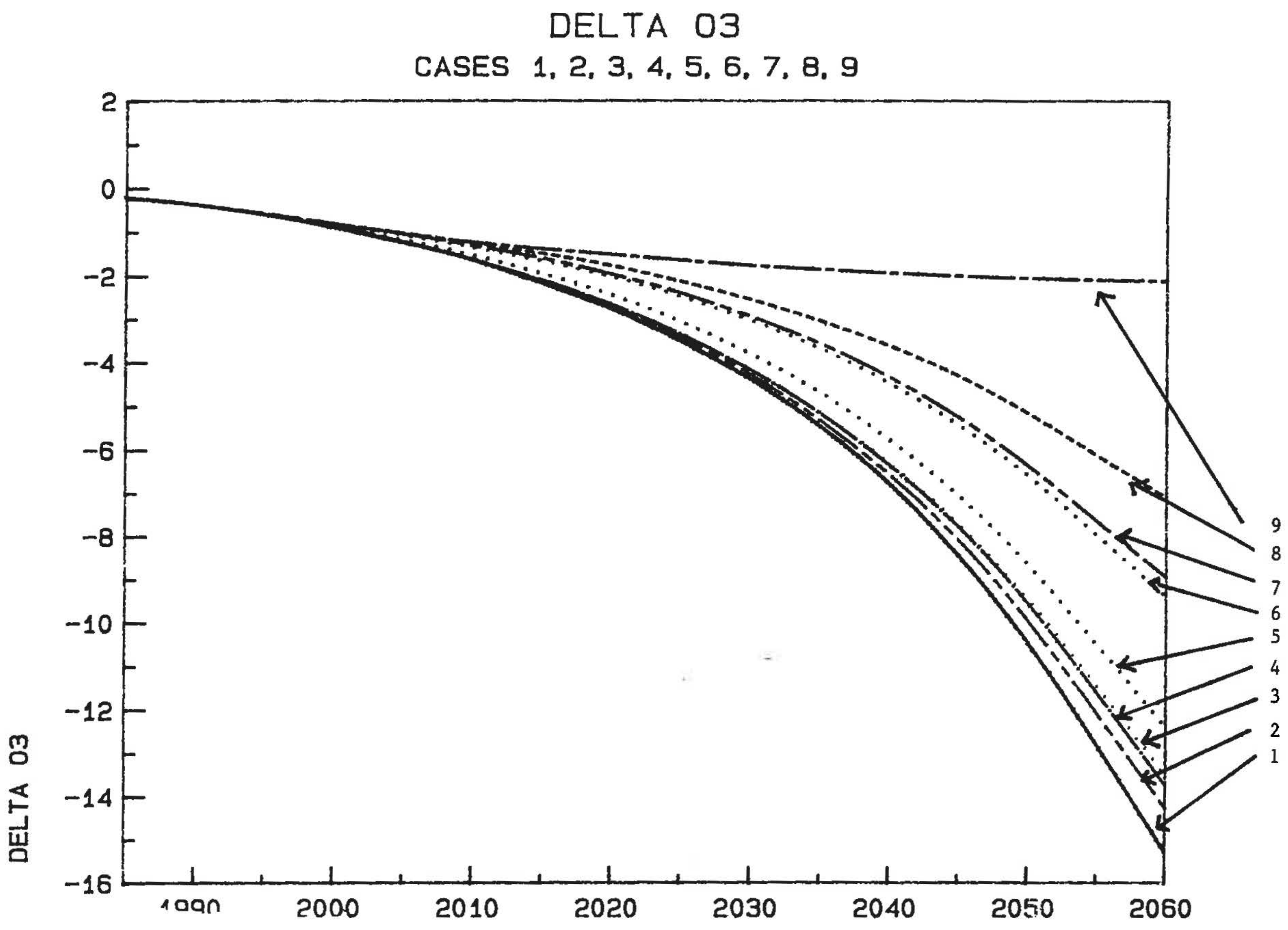

DELTA O3
CASES 1, 2, 3, 4, 5, 6, 7, 8, 9
DELTA O3
2
0
-2
-4
-6
-8
-10
-12
-14
-16
2000
2010
2020
2030
2040
2050
2060
9
8
7
6
5
4
3
2
1

FIG. 4a

CASE 9 ("FREEZE" 1990)

LINEAR METHANE GROWTH

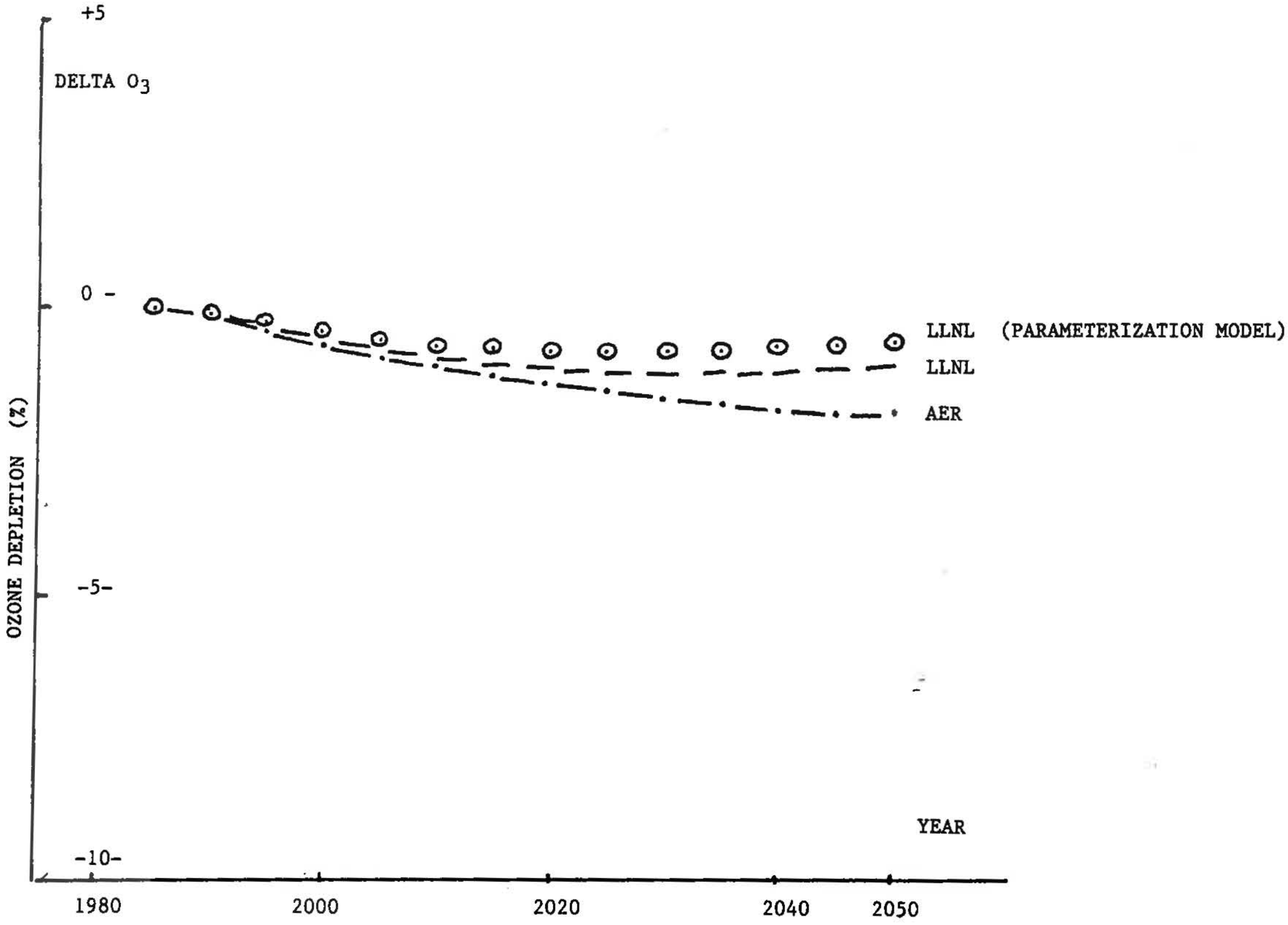


FIG. 4b CASE 1 LINEAR METHANE GROWTH

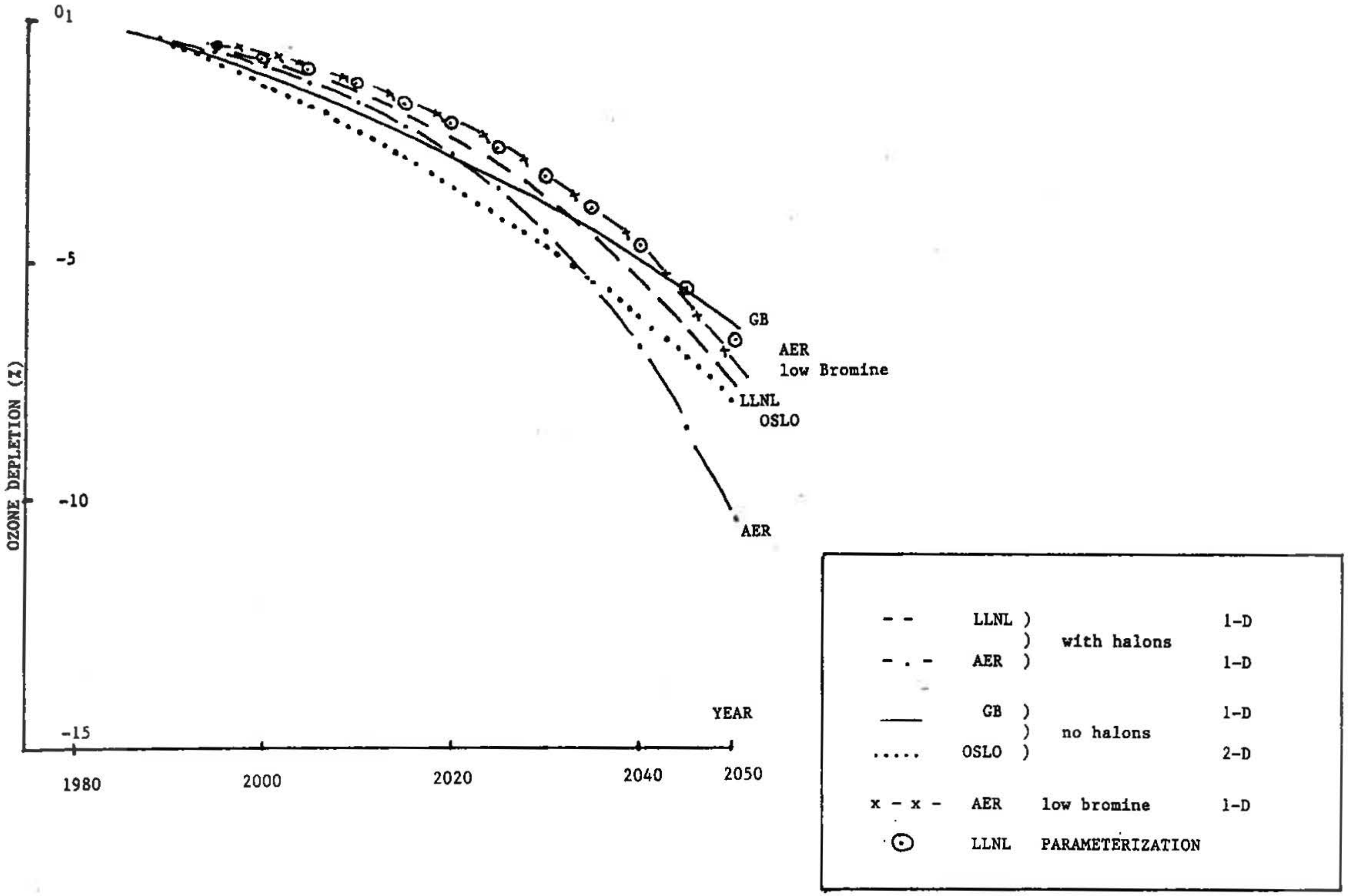


FIG. 4c CASE 2 COMPOUND METHANE GROWTH

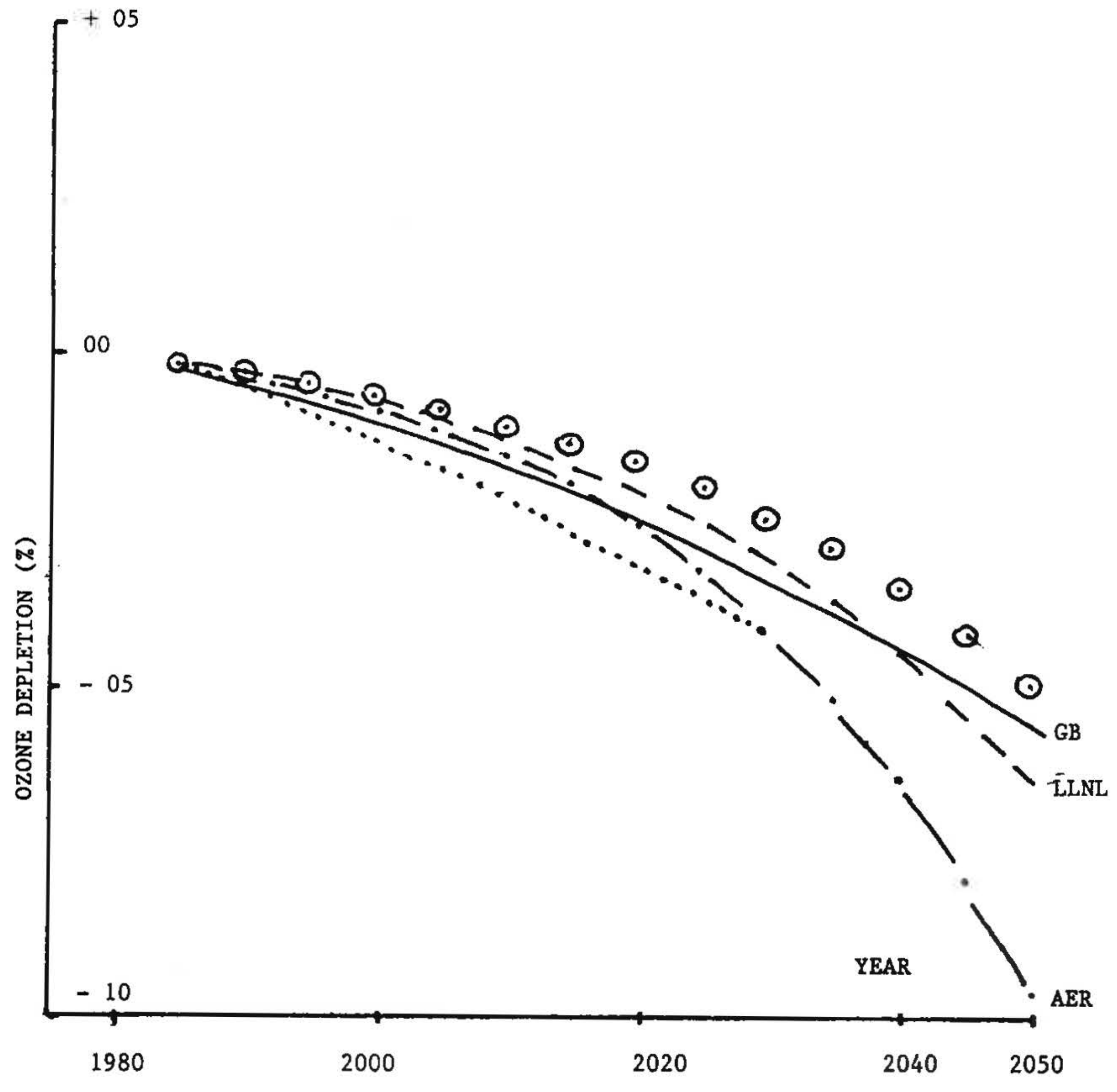


FIG. 4d CASE 8 LINEAR METHANE GROWTH

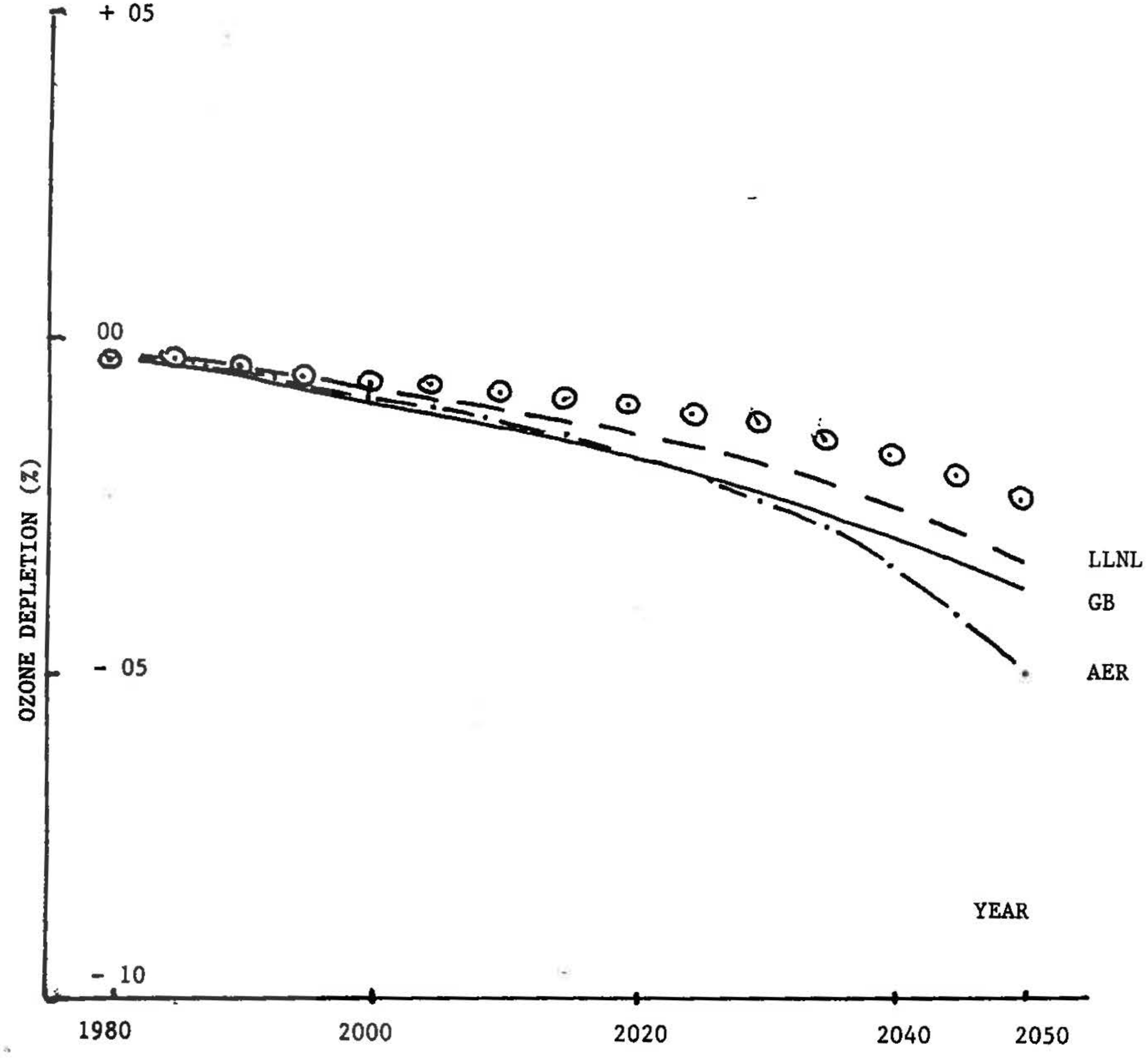


TABLE 1

OZONE DEPLETION POTENTIAL PER UNIT MASS OF
CHEMICAL EMITTED RELATIVE TO CFC-11
(AER and LLNL 1-D Models)

Chemical	Molecular Weight	Lifetimes (year)	Approx. Global Emission (million kg/yr)	Ozone Depletion Potential (AER)	Ozone Depletion Potential (LLNL)
CFC-11 ($CFCl_3$)	137.5	65	342	1	1
CFC-12 (CF_2Cl_2)	121	130	444	1.1	1.0
Carbon Tetrachloride (CCl_4)	154	50	1029	.92	1.06
CFC-113 ($C_2F_3Cl_3$)	187.5	90	163	.84	0.78
CFC-114 ($C_2F_4Cl_2$)	171	180	-	1.1	-
CFC-115 (C_2F_5Cl)	154.5	380	—	0.6	-
CFC-22 (CHF_2Cl)	86.5	20	207	.08	0.05
Methyl chloroform ($C_2H_3Cl_3$)	133.5	7.0	545	.13	0.10
Methylene chloride (CH_2Cl_2)	85	0.28	-	$3x10^{-3}$	-
Halon 1301 ($CBrF_3$)	149	110	~ 10	8	11.4
Halon 1211 (CF_2BrCl)	165.5	25	~ 10	2	~ 5

Because of the much higher efficiency of the bromine cycle, the calculated ODP for H-1301 and H-1211 are significantly larger than unity. As in the case of bromine, ozone is removed by the reaction of BrO with ClO, the calculated ODP for the Halons will depend on the chlorine burden in the stratosphere. The values in table (1) are calculated using the present-day chlorine burden of about 2.8 ppbv.

7. Changes in ozone profile

Attention was also drawn to the fact that in all cases of ozone depletion even when zero or negative (ozone increase) there would occur significant redistribition of ozone in the vertical column with an increase in tropospheric ozone and a decrease in stratospheric ozone occurring. Figs. 5 and 6 show that for Case 9, a freeze of ozone depleting substances at 1990 levels, stratospheric ozone depletion is accompanied by ozone increases in the troposphere. Fig. 5 indicates the percentage ozone change and Fig. 6 the predicted quantitative change with altitude. Such changes would imply consequences for climate (ozone is a greenhouse gas) and in cases of ozone increase at near surface levels consequences for human health and ecosystems related to the formation of photochemical smog.

The Experts participating in the meeting were of the opinion that the scenarios generated by USEPA should be supplemented by a limited number of other scenarios which were more straight forward, and similar to those used in the CCOL 1986 report, thus allowing comparisons, viz:

(a) 1.5% per year growth in all Fully Halogenated Halocarbons (CCOL considered only 11 + 12) (Base 1985)

(b) As (a) but 3.0% per year

(c) Freeze 11, 12, 113 allow 3% per year growth in Halons

(d) Freeze 11, 12, allow 3% per year growth in 113 and Halons

(e) Freeze all fully halogenated compounds in developed world - allow 3% per year growth in developing world assuming that in 1985 developing countries used 25% of total

(f) Same as (e) but assume developing countries only used 10% of total in 1985

These scenarios were run using the parameterization model, and the ozone depletion pedicted are shown in Fig. X.

FIG. 5

"1990 FREEZE"

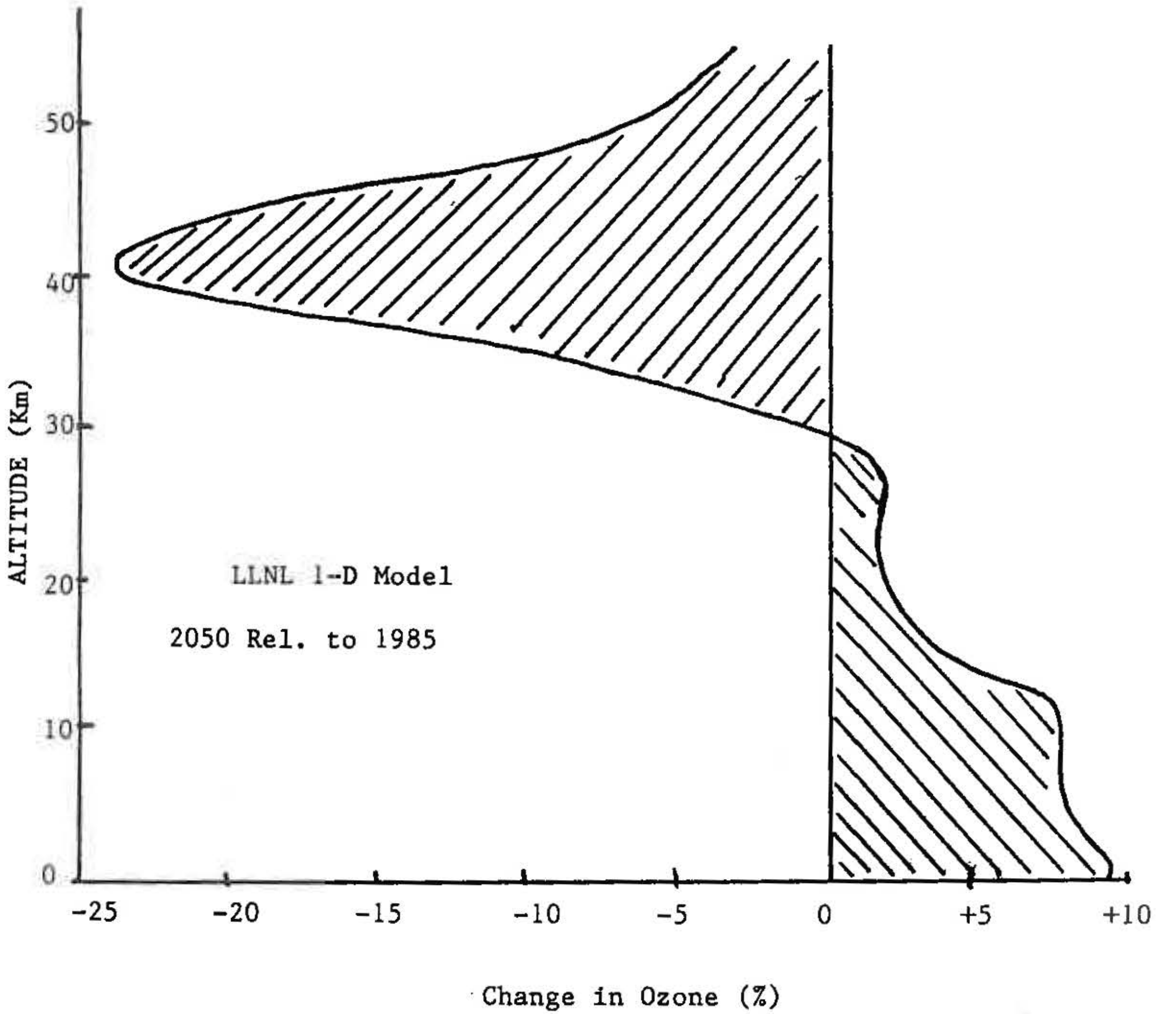
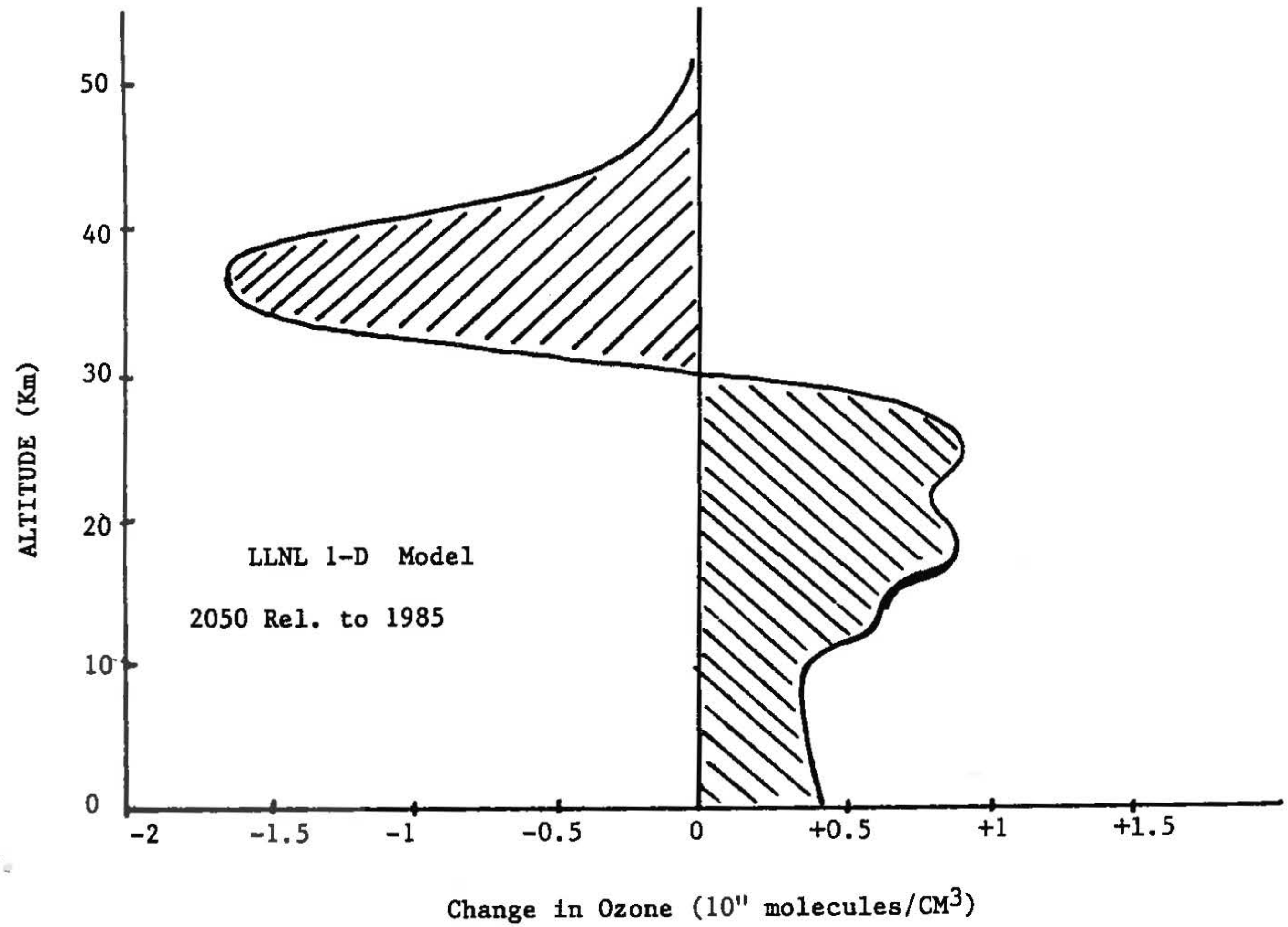


FIG. 6

"1990 FREEZE"



ANNEX I

ARTICLE II: CONTROL MEASURES*

1. Each party, under jurisdiction of which substances referred to in Annex A are produced shall ensure that within [1 - 3] years after the entry into force of this Protocol the [annual production and imports] [adjusted annual production] of these substances does (do) not exceed its (their) 1986 level.

2. Each party, under the jurisdiction of which substances referred to in Annex A are not produced at the time of the entry into force of this Protocol, shall ensure that within [1 - 3] years hereinafter [its annual production and imports] [its adjusted annual production] do not exceed the level of imports in 1986.

3. Each party shall ensure, that within [..] years after the entry into force of this Protocol levels attained in accordance with paragraphs 1 and 2 will be reduced by [10 - 50] percent [,unless the parties by a two-thirds majority otherwise decide] [if the parties confirm this obligation by a two-thirds majority].

Option A

4. Parties shall decide not later than [..] years after the entry into force of this Protocol by a two-thirds majority on

- new substances to be included in Annex A
- further reductions of 1986 levels.

These decisions shall be reviewed in intervals of [..] years.

Option B

4. Each party shall ensure that within [..] years after the entry into force of this Protocol levels attained in accordance with paragraph 3 will be reduced by [ ] unless parties by a two-thirds majority otherwise decide if parties confirm this obligation by a two-thirds majority .

*- Numbers used are only illustrative.
 - This Article has to be reconsidered in the light of any provisions related to trade.