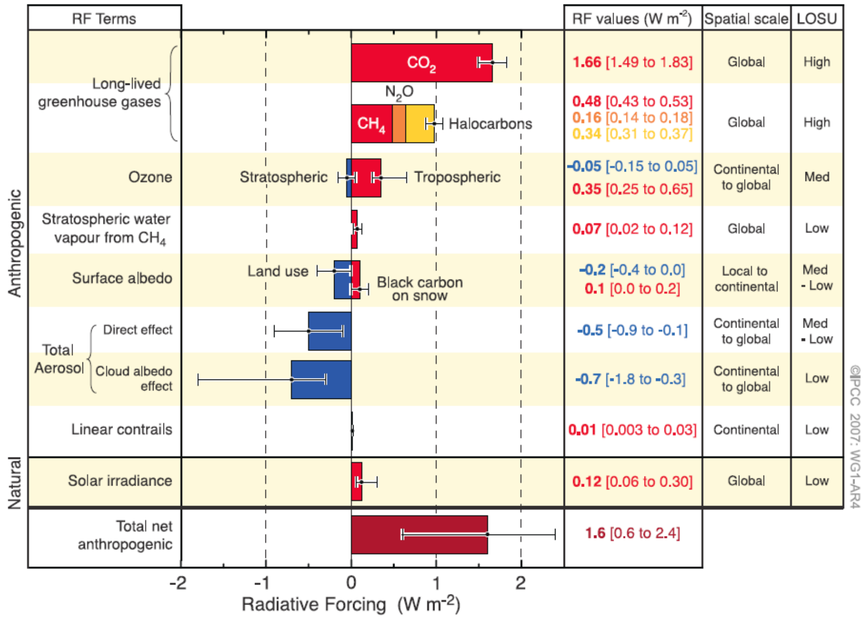
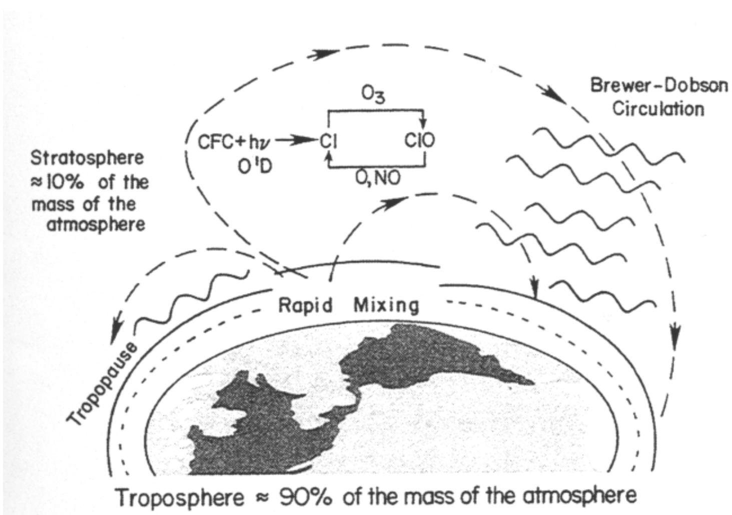


Industrial Designation or Common Name (years)	Chemical Formula	Lifetime (years)	Radiative Efficiency (W m⁻² ppb⁻¹)	Global Warming Potential for Given Time Horizon SAR‡ (100-yr)	20-yr	100-yr	500-yr
Carbon dioxide	CO_2	See below[a]	[b]1.4x10⁻⁵	1	1	1	1
Methane[c]	CH_4	12[c]	3.7x10⁻⁴	21	72	25	7.6
Nitrous oxide	N_2O	114	3.03x10⁻³	310	289	298	153
Substances controlled by the Montreal Protocol							
CFC-11	CCl_3F	45	0.25	3,800	6,730	4,750	1,620
CFC-12	CCl_2F_2	100	0.32	8,100	11,000	10,900	5,200
CFC-13	$CClF_3$	640	0.25		10,800	14,400	16,400
CFC-113	CCl_2FCClF_2	85	0.3	4,800	6,540	6,130	2,700
CFC-114	$CClF_2CClF_2$	300	0.31		8,040	10,000	8,730
CFC-115	$CClF_2CF_3$	1,700	0.18		5,310	7,370	9,990
Halon-1301	$CBrF_3$	65	0.32	5,400	8,480	7,140	2,760
Halon-1211	$CBrClF_2$	16	0.3		4,750	1,890	575
Halon-2402	$CBrF_2CBrF_2$	20	0.33		3,680	1,640	503
Carbon tetrachloride	CCl_4	26	0.13	1,400	2,700	1,400	435
Methyl bromide	CH_3Br	0.7	0.01		17	5	1
Methyl chloroform	CH_3CCl_3	5	0.06		506	146	45
HCFC-22	$CHClF_2$	12	0.2	1,500	5,160	1,810	549
HCFC-123	$CHCl_2CF_3$	1.3	0.14	90	273	77	24
HCFC-124	$CHClFCF_3$	5.8	0.22	470	2,070	609	185
HCFC-141b	CH_3CCl_2F	9.3	0.14		2,250	725	220
HCFC-142b	CH_3CClF_2	17.9	0.2	1,800	5,490	2,310	705
HCFC-225ca	$CHCl_2CF_2CF_3$	1.9	0.2		429	122	37

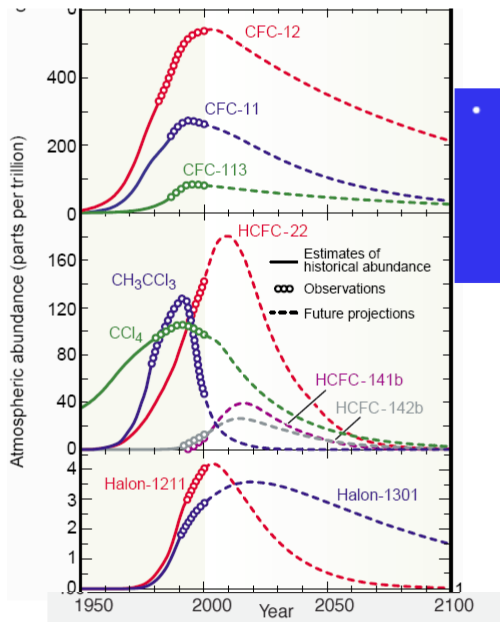
IPCC (2007) Table 2.14

Industrial Designation or Common Name (years)	Chemical Formula	Lifetime (years)	Radiative Efficiency (W m⁻² ppb⁻¹)	Global Warming Potential for Given Time Horizon			
				SAR‡ (100-yr)	20-yr	100-yr	500-yr
Hydrofluorocarbons							
HFC-23	CHF_3	270	0.19	11,700	12,000	14,800	12,200
HFC-32	CH_2F_2	4.9	0.11	650	2,330	675	205
HFC-125	CHF_2CF_3	29	0.23	2,800	6,350	3,500	1,100
HFC-134a	CH_2FCF_3	14	0.16	1,300	3,830	1,430	435
HFC-143a	CH_3CF_3	52	0.13	3,800	5,890	4,470	1,590
HFC-152a	CH_3CHF_2	1.4	0.09	140	437	124	38
HFC-227ea	CF_3CHFCF_3	34.2	0.26	2,900	5,310	3,220	1,040
HFC-236fa	$CF_3CH_2CF_3$	240	0.28	6,300	8,100	9,810	7,660
HFC-245fa	$CHF_2CH_2CF_3$	7.6	0.28		3,380	1030	314
HFC-365mfc	$CH_3CF_2CH_2CF_3$	8.6	0.21		2,520	794	241
HFC-43-10mee	$CF_3CHFCHFCF_2CF_3$	15.9	0.4	1,300	4,140	1,640	500
Perfluorinated compounds							
Sulphur hexafluoride	SF_6	3,200	0.52	23,900	16,300	22,800	32,600
Nitrogen trifluoride	NF_3	740	0.21		12,300	17,200	20,700
PFC-14	CF_4	50,000	0.10	6,500	5,210	7,390	11,200
PFC-116	C_2F_6	10,000	0.26	9,200	8,630	12,200	18,200
PFC-218	C_3F_8	2,600	0.26	7,000	6,310	8,830	12,500
PFC-318	$c\text{-}C_4F_8$	3,200	0.32	8,700	7,310	10,300	14,700
PFC-3-1-10	C_4F_{10}	2,600	0.33	7,000	6,330	8,860	12,500
PFC-4-1-12	C_5F_{12}	4,100	0.41		6,510	9,160	13,300
PFC-5-1-14	C_6F_{14}	3,200	0.49	7,400	6,600	9,300	13,300
PFC-9-1-18	$C_{10}F_{18}$	>1,000[d]	0.56		>5,500	>7,500	>9,500
trifluoromethyl sulphur pentafluoride	SF_5CF_3	800	0.57		13,200	17,700	21,200

Breakdown of CFCs in the stratosphere and catalytic destruction of ozone



Past and future abundance of atmospheric halogen gases



- **Current trends:**

  CFCs decreasing or stable (0 to -3%/year)

  HCFCs increasing (+1 to +3%/year)

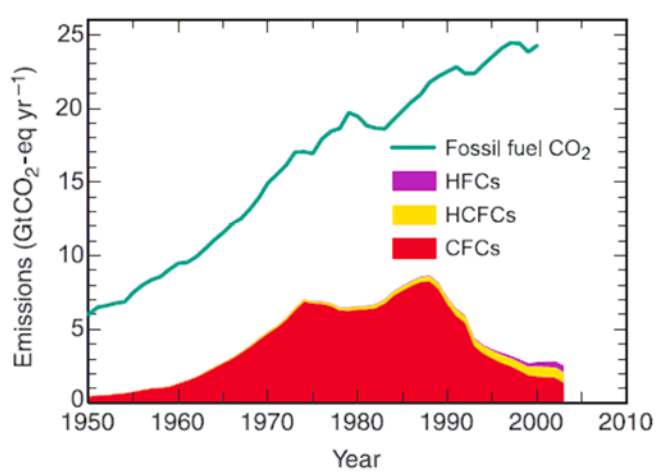
WMO, 2002

Halocarbon emissions – weighted by GWP

Combined CO_2-equivalent emissions from halocarbons:

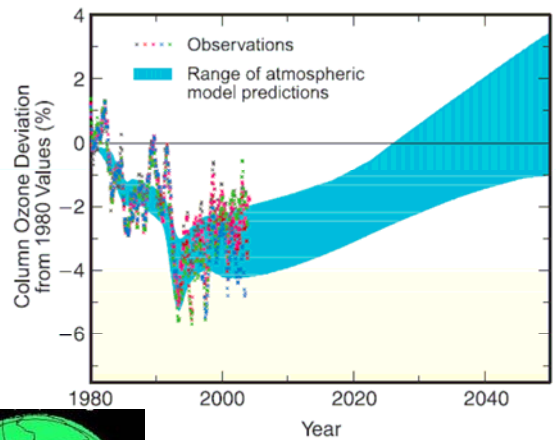
~7.5 Gt near 1990, about 33% of that year's CO_2 emissions from global fossil fuel burning

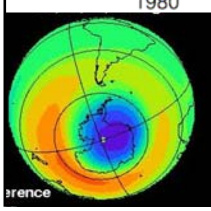
~2.5 Gt near 2000, about 10% of that year's CO_2 emissions from global fossil fuel burning



IPCC, Safeguarding the Ozone Layer and the Global Climate System (2005)

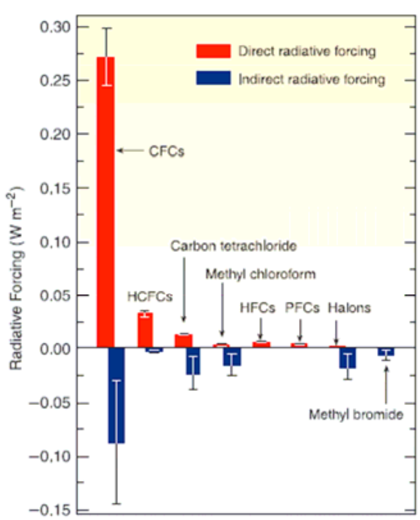
Indirect effect of halocarbons: Stratospheric ozone depletion





- Decreasing ozone linked mainly to CFCs
- Variable from year to year
- Ozone depletion is a cooling influence on climate. Warming due to CFCs and cooling due to ozone depletion may not occur in the same places or times.
- Recovery in 21st century

Radiative forcing due to changes in halocarbons

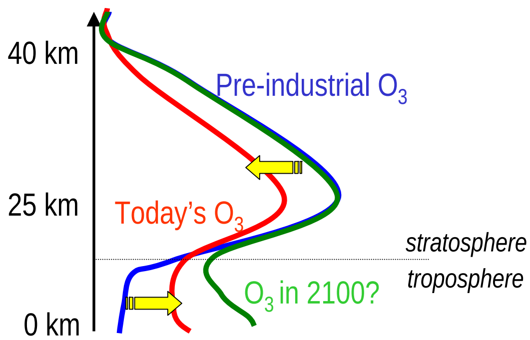


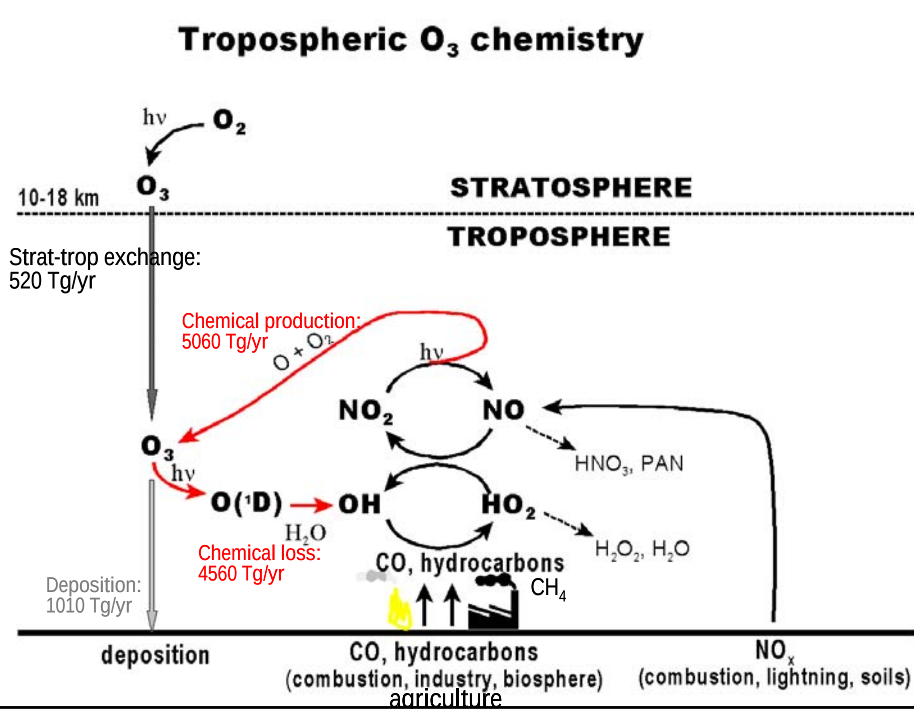
Direct radiative forcing: +0.32±0.03 W/m^2
Indirect radiative forcing: -0.15±0.10 W/m^2

Radiative forcing due to changes in ozone since pre-industrial times

- Observed losses of **stratospheric ozone** layer over last two decades (~5%): ➔ negative forcing (cooling) of -0.05 W m^{-2}

- Increase in **tropospheric ozone** since pre-industrial times (by 35-50%): ➔ positive forcing (warming) of 0.35 W m^{-2}





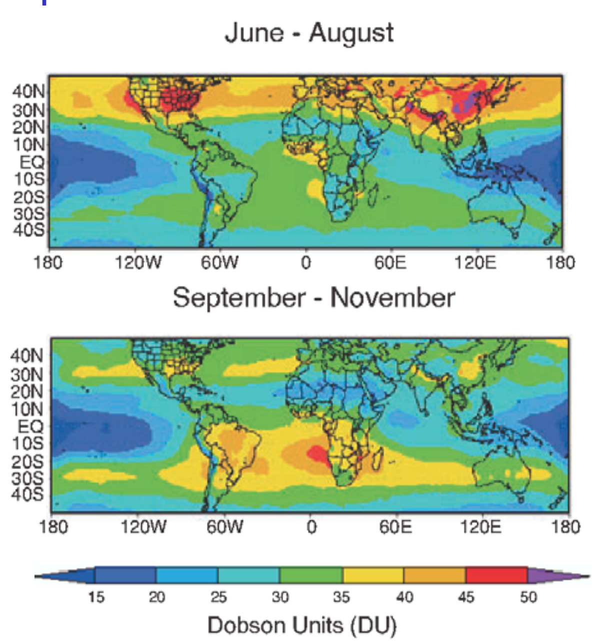
Sources of O_3 precursors

Sources	CH_4 (Tg/yr)	CO (Tg/yr)	NMHC (Tg C/yr)	NO_x (Tg N/yr)
Energy use	110 (65-155)	500 (300-900)	70 (60-100)	22 (20-24)
Aircraft				0.5 (0.2-1)
Biomass burning	40 (10-70)	500 (400-700)	40 (30-90)	8 (3-13)
Vegetation		100 (60-160)	400 (230-1150)	
Soils				7 (5-12)
Lightning				5 (2-20)
Ruminants	85 (60-105)			
Rice paddies	80 (30-120)			
Animal wastes	30 (15-45)			
Landfills	40 (20-60)			
NH_3 oxidation				0.9 (0-1.6)
N_2O breakdown*				0.6 (0.4-1)
Domestic sewage	25 (20-30)			
Wetlands	145 (115-175)			
Oceans	10 (5-15)	50 (20-200)	50 (20-150)	
Freshwaters	5 (1-10)			
CH_4 hydrates	10 (5-15)			
Termites	20 (1-40)			
Total	**600** (520-680)	**1150** (780-1960)	**560** (340-1490)	**44** (30-73)
Contribution from anthropogenic sources	~ 70%	~ 85%	~ 20%	~ 70%

* NO_y produced in the stratosphere and transported to the troposphere.

WMO, Scientific Assessment of Ozone Depletion, 1998

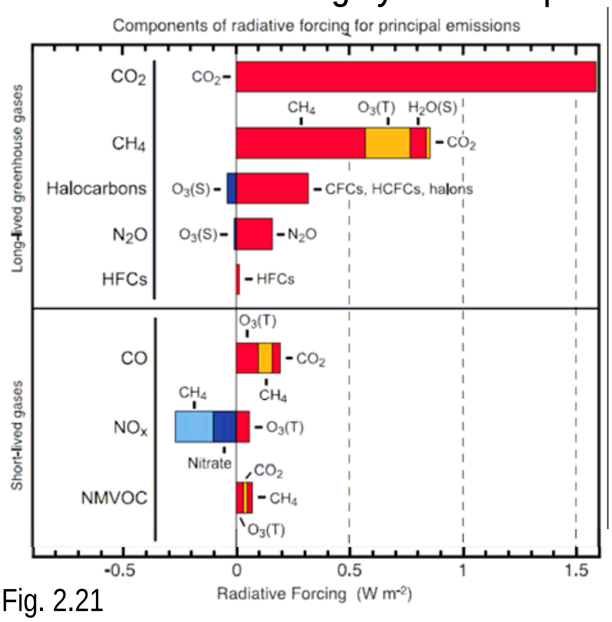
Tropospheric ozone column seen from space



Change in tropospheric ozone since pre-industrial era

- O_3 is reactive: no ice core record.
- Surface measurements in 19th and early 20th century in Europe: much lower O_3 (10-20 ppbv) than today (40-50 ppbv), and different seasonal cycle. But relationship to Northern Hemisphere concentrations not obvious.
- Global chemical transport models imply a 50% increase in Northern Hemisphere O_3 since pre-industrial era due to increases in emissions of NO_x, CO, CH_4 and hydrocarbons.

Global mean radiative forcing by emission precursor



Indirect GHG

IPCC (2007) Fig. 2.21