Review of CFC-11: Metadata on Distributed Emissions

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Emission Functions

CFC-11 (CCl_3F, trichlorofluoromethane) is now used primarily within rigid plastic insulating foams ("closed cell foams"). Some material is released into the atmosphere when the foam is first blown but most of the losses occur in the long term due to gradual migration of the insulating gas through the cell walls, with total loss when the equipment is finally removed from service and scrapped. There are other minor uses in refrigeration and historical use in aerosol propellant formulations.

As a consequence of the delay between first use and release, it is necessary to calculate emissions from time series of data on production and sales into various end-use categories having different release functions. The calculation method is described in McCulloch *et al*. (2001).

The rate of emission from closed cell foams varies with the nature of the plastic matrix. However, for most of the period over which emissions have occurred, the release has been parameterised by a single function covering all matrices: some 10% of the CFC-11 used was lost during the blowing process and the remainder was released linearly over 20 years (at 4.5%/year) (Gamlen *et al*., 1986). Since the early 1990s, it has become apparent that this is now overstating the release rate and a constant rate of loss (3.66%/yr) from the accumulated bank in such foams (with no additional initial loss) has been used since 1994 (Ashford, 2000 and McCulloch *et al*., 2001)

The emission function for refrigeration has an approximately normal distribution about a 4.5 year mean and complete emission within 10 years. The emission function for aerosols and others provides for 50% release in the year of manufacture and the rest in the year following and the corresponding value for open cell foam is 83% in the year of manufacture. Emissions do not depend on the season of the year.

Basic Data on Sales

There is no single data set for global sales of any of the fluorocarbons. That compiled by industry (AFEAS, 2001) is compound specific and audited to ensure quality control, but has incomplete geographical coverage; production in China, India, Korea and Russia is not included. The data on production and consumption (the latter equating to sales) compiled by the United Nations Environment Programme to verify the application of the Montreal Protocol are neither compound specific nor audited although they do cover all parties to the Protocol (UNEP, 2002). UNEP data are reported as the aggregate total of all CFCs in ODPtonnes (Ozone Depletion Potential multiplied by metric tonnes). Submissions by individual countries are incorporated into the UNEP database with no further checks and reported values have been revised, without explanation, several years after they were first submitted. Such changes have had a small effect on the CFC-11 data set, resulting in minor changes from the values published in McCulloch *et al.* (2001). Nevertheless, amalgamation of the data sets to provide global consumption values with defined quality and uncertainty was accomplished substantially as described in that work.

Geographical Distribution of Emissions

The calculated global emissions of CFC-11 were distributed among countries using the distribution of individual national fractions of the world total Gross Domestic Product, as described in McCulloch *et al.* (1994). Within each country, emissions were distributed to individual gridsquares using a population distribution from Harvard University (Jennifer Logan, *personal communication*).

Results are presented here as the percentage distribution among gridsquares. Absolute emission from each gridsquare in 1986 should be calculated by multiplying global emission for 1986 in Table 1 (CFC11EM) by the gridsquare percentages in Table 2 (CFC1186yr1.1a). For other years, the distribution in Table 2 should be applied to the global emission for the appropriate year. While global emissions change relatively rapidly, distribution is affected only by relative economic activity and population dynamics, which have slower rates of change with time. It is expected that the distribution can be applied to the years 1980 to 1990 without significantly increasing uncertainty but this has not been tested. It can be applied to years beyond this range only with caution and new distributions for more recent years are under development.

Time Series of Global Emissions

Based on McCulloch et al. (2001) the time series (1933 to 2000) of CFC-11 emissions and their uncertainties is shown in Table 1 . From the years 1986 to 2000, the values are slightly different from those reported in the literature. This is due to an unexplained change in the UNEP database between successive publications in 1996 and 2002 which altered the quantities not included in the AFEAS database. The maximum annual difference between the published data and that recorded here is 5% and the two data sets are not significantly different at the 95% confidence level.

Future emissions will be governed by the controls required by the Montreal Protocol and by the quantity of material currently in the "bank" (that is: material which is in use but has not yet been emitted). A scenario for future releases of CFC-11 was described in Madronich and Velders (1999). This scenario has been updated and will be published in Fraser and Montzka (2003).

Development

In view of the changes brought about by the Montreal Protocol, it is proposed to revise the distribution functions to provide gridded data for the year 2000.

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Table

Global Emissions of CFC-11 (trichlorofluoromethane) from 1933 to 2000			
Year	**Annual CFC-11 emission, Mg**		
	Mean	**+ 2SD**	**- 2SD**
1933	0		
1934	4	4	3
1935	8	9	7
1936	35	38	32
1937	35	38	32
1938	51	55	46
1939	69	75	62
1940	91	100	83
1941	116	127	105
1942	145	158	131
1943	187	204	169
1944	231	252	209
1945	279	304	253
1946	642	701	582
1947	1268	1386	1150
1948	2332	2549	2115
1949	3806	4160	3451
1950	5487	5999	4976

1951	7633	8195	7070
1952	10985	11453	10517
1953	14955	15472	14439
1954	18576	19223	17929
1955	23019	23770	22269
1956	28709	29566	27852
1957	32161	33243	31078
1958	30158	31499	28817
1959	30888	32370	29407
1960	40550	42347	38753
1961	52133	54163	50103
1962	65380	67647	63112
1963	80029	82475	77584
1964	94997	97608	92386
1965	108294	110966	105622
1966	121273	124246	118301
1967	137642	140743	134542
1968	156791	160018	153564
1969	181984	185598	178369
1970	206875	210879	202872
1971	227475	231885	223066
1972	256593	261717	251469
1973	293811	299799	287824
1974	323601	330194	317009
1975	314114	320068	308160
1976	321131	328692	313569

1977	309408	317203	301613
1978	290508	298998	282019
1979	272147	281301	262992
1980	261009	269857	252162
1981	259934	268008	251861
1982	255443	263792	247095
1983	271010	279271	262749
1984	292078	300786	283370
1985	305047	313650	296444
1986	323573	332971	314175
1987	342445	354046	330843
1988	349890	364259	335520
1989	304084	318091	290077
1990	257663	270446	244879
1991	229984	243222	216746
1992	212071	227362	196779
1993	198974	217076	180872
1994	118528	133724	103332
1995	106178	124086	88270
1996	100609	120309	80910
1997	92385	112929	71841
1998	84719	105976	63462
1999	79376	102842	55910
2000	74768	99948	49588

Table 1: Global Emissions of CFC-11 (trichlorofluoromethane) from 1933 to 2000

Data in Mg (millions of grams or metric tonnes), SD=Standard Deviation
Compiled by A. McCulloch (archie@marbury.u-net.com)

Based on:
McCulloch A., P. Ashford and P.M. Midgley
Historic Emissions of Fluorotrichloromethane (CFC-11) Based on a Market Survey
Atmos. Environ., 35(26), 4387-4397, 2001

Production, Sales and Atmospheric Releases of Fluorocarbons through 2000,
Alternative Fluorocarbons Environmental Acceptability Study, Arlington, VA, USA, 2001.

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