MIT Joint Program on the
Science and Policy of Global Change

Historical Anthropogenic Emissions Inventories for Greenhouse Gases and Major Criteria Pollutants

Malcolm O. Asadoorian, Marcus C. Sarofim, John M. Reilly, Sergey Paltsev and Chris Forest

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Abstract

We assemble a data set on historical anthropogenic emissions of greenhouse gases (CO_2, CH_4, N_2O, PFC, SF6, HFC, and CFC) and other radiatively important substances (SO_2, NO_X, CO, VOC, BC, OC, and NH_3) for the period from 1890 to 1995. The objective is to develop data series for emissions suitable to force the Massachusetts Institute of Technology (MIT) Integrated Global System Model (IGSM). It is an earth system model of intermediate complexity that, for forward simulations, is driven by anthropogenic emissions as projected by the Emissions Prediction and Policy Analysis (EPPA) model. We develop spatially distributed emissions dataset for the historical period. For the most part, historic estimates of emissions of these substances are available in the literature and, hence, the contribution of this report is to assemble various data sets in a common format (matching the 16 country/regions in EPPA and 5-year resolution of the model), and to document the sources for these estimates. With this data resolution we can make calculations consistent with forward simulations of MIT IGSM, using a post-processor for the EPPA model to distribute emissions at the spatial and temporal resolutions required for the earth systems components of the model.

Contents

1. INTRODUCTION

General Circulation Models' (GCMs) predictive skill in forecasting climate is typically evaluated by driving them with observed changes in radiative forcing for the last 150 years or so and comparing the predicted climate against the actual climate. Earth system models include not only a representation of climate but also atmospheric chemistry, land, and ocean processes, with the goal of predicting concentrations of gases and aerosols given changes in emissions. Thus, to evaluate these components of earth system models, it is useful to drive them with estimates of historical emissions. In doing so, one can evaluate the predictive skill in terms of the model's ability to predict concentrations of each of several greenhouse substances, as well as the ability of the climate component to accurately simulate radiative forcing and climate effects. Evaluating the earth system model in this way tests the representation of feedback mechanisms among components which would not be assessed by testing each component alone.

Our objective in this paper is to develop an emissions data series suitable to force the Massachusetts Institute of Technology (MIT) Integrated Global System Model (IGSM), an earth system model of intermediate complexity (Sokolov *et al.*, 2005). The anthropogenic component of MIT IGSM is the Emissions Prediction and Policy Analysis (EPPA) model (Paltsev *et al.,* 2005). It is a recursive-dynamic multi-regional general equilibrium model of the world economy, which is built on the Global Trade Analysis Project (GTAP) version 5 database (Hertel, 1997; Dimaranan and McDougall, 2002) and additional data for advanced energy and transportation technologies. As presented in **Table 1**, the EPPA version 4 (*i.e.* EPPA4) model includes 16 countries/regions, 6 non-energy sectors, and 15 energy sectors/technologies. The base year of data utilized by EPPA4 is 1997 and it produces anthropogenic emissions projections of greenhouse gases, aerosols, and other air pollutants and their precursors through the year 2100.

In this report, we assemble data on historical anthropogenic emissions of greenhouse gases (CO_2, CH_4, N_2O, PFC, SF6, HFC, and CFC) and other radiatively important substances (SO_2, NO_X, CO, VOC, BC, OC, and NH_3) for the period 1890 to 1995. The choice of the starting period is determined by available data. Moreover, the choice of the data format is determined by the EPPA model output, which is used for future emissions projections in the IGSM. While the economic model operates with five-year time steps and a regional geographic scale, the coupled ocean-atmosphere-land component of the MIT IGSM requires daily emissions on a four degree latitudinal scale. Therefore, a post-processor in the EPPA model distributes emissions on a 1 x 1 degree grid proportionally within each region to population in the year 1995 (CIESIN, 2000) and interpolates the data between 5-year-step EPPA data points, maintaining consistency with the methodology we use for future projections. It is convenient to use this post-processor for the historical simulations. Thus, we modify historical anthropogenic emissions data from literature sources to be consistent with the EPPA format; specifically, at five-year time steps from 1890 to 1995 for each of the 16 countries/regions in EPPA4. We also report the global totals for each time step. Maintaining consistency with the units in EPPA, most of the data are presented in million metric ton (*mmt*), equivalent to the unit of Teragram (*Tg*), or 10^{12} gram. For F-gases, the unit is thousand metric tons (*tmt*), which is equivalent to Gigagram (*Gg*), or 10^9 gram. The remainder of the sections is devoted to each of the emissions species.

Table 1. Countries, Regions, and Sectors in the EPPA4 Model.

Country or Region	Sectors
Annex B	***Non-Energy***
United States (USA)	Agriculture (AGRI)
Canada (CAN)	Services (SERV)
Japan (JPN)	Energy-Intensive products (EIT)
European Union+[a] (EUR)	Other Industries products (OTHR)
Australia & New Zealand (ANZ)	Transportation (TRAN)
Former Soviet Union[b] (FSU)	Household Transportation (HTRN)
Eastern Europe[c] (EET)	***Energy***
Non-Annex B	Coal (COAL)
India (IND)	Crude Oil (OIL)
China (CHN)	Refined Oil (ROIL)
Indonesia (IDZ)	Natural Gas (GAS)
Higher Income East Asia[d] (ASI)	Electric: Fossil (ELEC)
Mexico (MEX)	Electric: Hydro (HYDR)
Central & South America (LAM)	Electric: Nuclear (NUCL)
Middle East (MES)	***Advanced Energy Technologies***
Africa (AFR)	Electric: Biomass (BELE)
Rest of World[e] (ROW)	Electric: Natural Gas Combined Cycle (NGCC)
	Electric: NGCC with Sequestration (NGCAP)
	Electric: Integrated Gasification with Combined Cycle and Sequestration (IGCAP)
	Electric: Solar and Wind (SOLW)
	Liquid fuel from Biomass (BOIL)
	Oil from Shale (SYNO)
	Synthetic Gas from Coal (SYNG)

[a] The European Union (EU-15) plus countries of the European Free Trade Area (Norway, Switzerland, Iceland).
[b] Russia, Ukraine, Belarus, Latvia, Lithuania, Estonia, Azerbaijan, Armenia, Georgia, Kyrgyzstan, Kazakhstan, Moldova, Tajikistan, Turkmenistan, and Uzbekistan.
[c] Hungary, Poland, Bulgaria, Czech Republic, Romania, Slovakia, Slovenia.
[d] South Korea, Malaysia, Philippines, Singapore, Taiwan, Thailand.
[e] All countries not included elsewhere: Turkey, and mostly Asian countries.

2. HISTORICAL ANTHROPOGENIC EMISSIONS FOR GREENHOUSE GASES

For each of the emissions species, some form of regional aggregation of the global data is available. Base year 1997 EPPA4 regional shares were used to match these regional aggregation schemes to those directly compatible with EPPA4. There existed missing years in the historical data or they were reported at a periodicity different than the five-year time step of EPPA4. In these cases, missing observations were interpolated using a cubic interpolation methodology where possible, and where not, linear interpolation (Morton, 1964; Press *et al.*, 1992).

2.1 Carbon Dioxide (CO_2) Emissions

EPPA distinguishes between CO_2 emissions from the following main source/activity categories: fossil fuels, other industrial sources (*i.e.*, cement and lime production), and deforestation (*i.e.*, land use change).

2.1.1 CO_2 Emissions from Fossil Fuels

In terms of CO_2 emissions originating from fossil fuels, annual historical emissions data is available from Marland *et al.* (2005). These data are available at the global, national, and regional levels. The common time series in which data is available for all the EPPA4 regions is for years 1884 through 2002. **Table 2** illustrates these data.

Table 2. CO_2 Emissions from Fossil Fuels in Tg of C

YEAR	USA	CAN	MEX	JPN	ANZ	EUR	EET	FSU	ASI	CHN	IND	IDZ	AFR	MES	LAM	ROW	GLOBAL
1890	104.01	9.04	0.11	1.92	0.51	206.50	8.07	21.83	0.66	0.06	0.53	0.13	0.08	0.10	0.27	0.77	354.59
1895	123.93	10.78	0.25	3.02	0.81	223.39	10.30	27.86	1.17	0.05	0.93	0.23	0.91	0.10	0.65	1.21	405.60
1900	171.59	14.92	0.32	5.24	1.40	278.78	14.30	38.66	1.97	0.14	1.58	0.39	0.64	0.28	0.82	2.10	533.11
1905	256.08	22.27	0.85	7.45	1.99	301.57	15.41	41.67	2.98	0.85	2.38	0.60	2.80	0.42	2.19	2.98	662.48
1910	331.65	28.84	1.65	10.28	2.74	351.24	19.26	52.07	4.29	5.53	3.43	0.86	4.79	0.51	4.24	4.11	825.49
1915	358.15	31.14	1.37	13.16	3.51	337.10	19.95	53.93	5.72	5.02	4.57	1.14	5.41	0.57	3.53	5.26	849.54
1920	450.45	39.17	1.95	17.11	4.56	333.87	12.08	32.65	6.69	8.02	5.35	1.34	7.72	0.74	5.02	6.85	933.57
1925	447.79	38.94	2.96	19.19	5.12	376.10	12.55	33.94	8.04	10.52	6.43	1.61	8.90	1.33	7.61	7.68	988.70
1930	452.33	39.33	3.05	20.36	5.43	404.27	20.67	55.89	9.13	12.43	7.31	1.83	9.51	1.72	7.85	8.15	1059.28
1935	388.69	33.80	3.86	24.70	6.59	381.14	31.58	85.39	8.59	18.50	6.87	1.72	10.32	4.00	9.92	9.88	1025.52
1940	493.47	42.91	5.83	31.86	8.50	423.28	56.88	153.79	11.80	29.51	9.44	2.36	15.26	6.54	15.00	12.74	1319.18
1945	613.31	53.33	5.80	20.50	5.47	224.85	37.60	101.66	9.83	13.93	7.86	1.97	18.43	10.99	14.92	8.20	1148.64
1950	676.12	58.79	12.59	27.24	7.26	425.21	67.29	181.94	14.09	22.16	11.27	2.82	25.73	4.67	32.37	10.89	1580.43
1955	726.78	63.20	18.58	36.58	9.75	544.57	101.10	273.36	21.14	55.23	16.91	4.23	35.30	13.75	47.78	14.63	1982.88
1960	783.08	68.09	23.41	54.71	14.59	607.46	140.07	378.72	28.29	221.80	22.63	5.66	42.68	24.86	60.19	21.89	2498.13
1965	928.70	80.76	28.47	85.84	22.89	743.10	183.65	496.54	40.67	146.00	32.54	8.13	58.25	47.45	73.21	34.34	3010.54
1970	1146.18	99.67	39.68	147.94	39.45	866.24	224.75	607.65	58.91	237.98	47.13	11.78	81.76	74.56	102.05	59.18	3844.90
1975	1170.44	101.78	50.47	171.17	45.64	885.84	281.21	760.31	78.62	347.82	62.89	15.72	104.22	114.45	129.78	68.47	4388.83
1980	1267.41	110.21	70.07	188.14	50.17	967.36	326.46	882.66	117.04	443.60	93.64	23.41	141.59	144.01	180.18	75.26	5081.20
1985	1209.45	105.17	69.52	190.09	50.69	896.04	356.05	962.65	150.02	583.04	120.02	30.00	168.31	178.51	178.77	76.04	5324.37
1990	1314.04	114.26	81.70	225.23	60.06	912.15	336.36	909.43	215.32	730.04	172.26	43.06	175.36	227.52	210.09	90.09	5816.97
1995	1421.22	123.58	91.51	240.85	64.23	864.87	231.82	626.76	301.95	954.07	241.56	60.39	201.60	322.95	235.32	96.34	6079.00

2.1.2 CO_2 Emissions from Other Industrial Sources

CO_2 originating from other industrial sources are mostly due to cement production, which is also part of the Marland *et al.* (2005) data. **Table 3** provides these data.

Table 3. CO_2 Emissions from Cement in Tg of C

YEAR	USA	CAN	MEX	JPN	ANZ	EUR	EET	FSU	ASI	CHN	IND	IDZ	AFR	MES	LAM	ROW	GLOBAL
1890	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1895	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1900	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1905	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1910	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1915	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1920	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1925	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1930	3.71	0.32	0.02	0.38	0.10	3.80	0.23	0.61	0.06	0.05	0.04	0.01	0.07	0.02	0.06	0.15	9.64
1935	1.73	0.15	0.07	0.54	0.14	4.23	0.26	0.71	0.08	0.13	0.06	0.02	0.17	0.06	0.19	0.21	8.75
1940	2.98	0.26	0.13	0.42	0.11	2.90	0.24	0.64	0.01	0.13	0.01	0.00	0.18	0.08	0.32	0.17	8.56
1945	2.39	0.21	0.16	0.17	0.05	1.72	0.10	0.26	0.15	0.03	0.12	0.03	0.26	0.09	0.42	0.07	6.21
1950	5.18	0.45	0.30	0.49	0.13	6.88	0.62	1.68	0.27	0.13	0.21	0.05	0.56	0.17	0.77	0.20	18.09
1955	7.13	0.62	0.48	1.06	0.28	10.81	1.22	3.29	0.49	0.70	0.39	0.10	0.95	0.37	1.24	0.42	29.56
1960	7.67	0.67	0.67	2.12	0.56	14.19	2.33	6.30	0.88	2.20	0.70	0.18	1.21	0.81	1.72	0.85	43.05
1965	9.09	0.79	0.91	3.06	0.82	19.78	3.61	9.76	1.44	1.95	1.15	0.29	1.57	1.22	2.35	1.22	58.99
1970	9.17	0.80	1.38	5.13	1.37	25.33	4.76	12.88	2.36	2.02	1.89	0.47	2.42	2.12	3.54	2.05	77.68
1975	8.98	0.78	2.01	5.85	1.56	27.15	6.25	16.89	3.39	5.15	2.71	0.68	3.02	3.55	5.17	2.34	95.49
1980	9.85	0.86	2.88	7.69	2.05	29.88	6.63	17.94	5.00	12.06	4.00	1.00	4.34	5.45	7.41	3.07	120.10
1985	10.12	0.88	2.71	6.52	1.74	25.76	6.54	17.68	6.97	20.67	5.58	1.39	5.67	8.71	6.98	2.61	130.51
1990	10.21	0.89	3.24	7.54	2.01	28.01	6.56	17.73	10.73	31.14	8.58	2.15	6.81	10.35	8.33	3.01	157.29
1995	10.93	0.95	3.70	8.01	2.14	24.77	3.22	8.70	15.98	67.84	12.78	3.20	8.38	13.18	9.52	3.20	196.50

2.1.3 CO_2 Emissions from Land Use Change

CO_2 emissions originating from land use change (mostly related to forestation and deforestation activities) appear in Houghton *et al.* (2002). This emissions category requires additional attention given the fact that, in the IGSM, the net terrestrial carbon flux is the combined result of a projected deforestation source from EPPA and carbon uptake by terrestrial systems as modeled by the Terrestrial Ecosystem Model (TEM) component (Felzer *et al.*, 2004). Some of the differences in estimates of the deforestation source that occur in the literature appear to stem from different ways of estimating "gross" emissions, such as the extent to which rapidly recycling terrestrial sources are included, or simply netted-out to zero. The net flux from land and uptake by the ocean also need to be consistent with the relatively well-measured changes in the atmospheric concentration and the fossil fuel source. The role of terrestrial systems in the carbon cycle is extensively documented in the IPCC Third Assessment Report (Houghton *et al.*, 2001). In addition, Sabine *et al.* (2004) provides a summary of recent estimates of global fluxes in the carbon cycle as summarized in **Table 4**, along with estimates of uncertainty in fluxes from terrestrial, atmosphere, and ocean carbon pools. Median estimates of the net sink center around –1.2 *Pg*C yr^{-1} for the 1990s, but with significant uncertainty. Moreover, there appears to be relatively less agreement about the land use change component of that sink, ranging from a median estimate of +0.9 *Pg*C yr^{-1} (DeFries *et al.*, 2002) to +2.2 *Pg*C yr^{-1} (Houghton *et al.*, 2003).

Table 4. The global carbon budget (PgC yr^{-1}) from Sabine *et al.* (2004)

	1980s	1990s
1. *Prentice et al. 2001*		
Atmospheric increase	+3.3 ± 0.1	+3.2 ± 0.1
Emissions (fossil fuel, cement)	+5.4 ± 0.3	+6.3 ± 0.4
Ocean-atmosphere flux	–1.9 ± 0.6	–1.7 ± 0.5
Net land-atmosphere flux	–0.2 ± 0.7	–1.4 ± 0.7
Land use change	+1.7 (+0.6 to +2.5)	—
Residual terrestrial sink	–1.9 (–3.8 to +0.3)	—
2. *Le Que′re′ et al. 2003*		
Ocean corrected	–1.8 ± 0.8	–1.9 ± 0.7
Net land-atmosphere flux	–0.3 ± 0.9	–1.2 ± 0.8
3. *Houghton 2003*		
Land use change	+2.0 (+0.9 to +2.8)	+2.2 (+1.4 to +3.0)
Residual terrestrial sink	–2.3 (–4.0 to –0.3)	–3.4 (–5.0 to –1.8)
4. *DeFries et al. 2002*		
Land use change	+0.6 (+0.3 to +0.8)	+0.9 (+0.5 to +1.4)
Residual terrestrial sink	–0.9 (–3.0 to 0)	–2.1 (–3.4 to –0.9
5. *Achard et al. 2002*		
Land use change		+1.0 ± 0.2
Residual terrestrial sink		–2.2 (–3.2 to –1.2)

Note: Positive values represent atmospheric increase (or ocean/land sources); negative numbers represent atmospheric decrease (sinks). Residual terrestrial sink determined by difference (net land/atmosphere flux minus land use change).

Houghton *et al.* (2002) data indicate a range of CO_2 emissions from land use change between +1.4 to +3.0 *Pg*C yr^{-1} with a median value of +2.2 *Pg*C yr^{-1}; the range of the residual terrestrial sink is -5.0 to -1.8 *Pg*C yr^{-1} with a median value of –3.4 *Pg*C yr^{-1}. The EPPA4 1997 base year global total of CO_2 emissions from land use change are based on estimates from Mayer *et al.* (2000) and are equal to the lower limit of Houghton *et al.* (2002) value of +1.4 *Pg*C yr^{-1}. The TEM component of MIT's IGSM provides EPPA4 with the residual terrestrial sink value of –2.1 *Pg*C yr^{-1} that is calibrated to the EPPA4 1997 base year global total of +1.4 *Pg*C yr^{-1}, thereby generating a net sink of –0.7 *Pg*C yr^{-1}. In order to use historic data from Houghton *et al.* (2002), as well as maintain consistency with the current calibration of the integrated model components of the IGSM, we have proportionally reduced the Houghton *et al.* (2002) estimates of CO_2 emissions from land use change for all years using the ratio of the global total of +2.2 *Pg*C yr^{-1} to +1.4 *Pg*C yr^{-1}. For our purposes of forcing a global earth system model, the regional source of CO_2 is not very important because it is a long-lived, and relatively well-mixed, gas.[1]

Table 5 provides the non-calibrated data for CO_2 emissions from land use change for each of the EPPA4 regions, the corresponding global totals, as well as the proportionally reduced global totals for IGSM calibration. The original data was converted from *Pg* to *Tg* in order to maintain consistency with the data reported in most of the other tables.

Table 5. CO_2 Emissions from Land Use Change in Tg of C

YEAR	USA	CAN	MEX	JPN	ANZ	EUR	EET	FSU	ASI	CHN	IND	IDZ	AFR	MES	LAM	ROW	GLOBAL	GLOB*
1890	240.44	13.30	5.95	7.93	3.97	30.32	12.99	56.57	52.13	38.98	65.16	13.03	15.56	13.14	85.65	1.98	657.10	421.22
1895	252.07	12.68	6.22	8.29	4.14	31.02	13.29	57.21	63.01	56.38	78.77	15.75	15.87	13.61	60.15	2.07	690.53	442.65
1900	247.06	12.08	6.53	8.70	4.35	31.63	13.56	57.79	64.58	64.36	80.72	16.14	16.07	14.04	56.93	2.18	696.71	446.61
1905	159.89	32.83	6.99	9.32	4.66	32.62	13.98	58.47	65.07	137.90	81.34	16.27	21.12	17.22	166.47	2.33	826.46	529.78
1910	117.56	44.97	7.46	9.95	4.97	33.85	14.51	58.54	70.51	170.92	88.14	17.63	21.68	17.86	182.03	2.49	863.05	553.24
1915	68.18	56.32	7.85	10.46	5.23	35.16	15.07	66.59	59.62	178.41	74.53	14.91	27.98	18.30	70.44	2.62	711.65	456.19
1920	37.77	61.21	8.18	10.90	5.45	36.62	15.70	73.05	60.97	198.96	76.22	15.24	28.61	18.44	56.66	2.73	706.71	453.02
1925	-24.35	64.26	8.51	11.34	5.67	38.09	16.33	79.78	60.78	213.85	75.98	15.20	34.92	18.47	135.36	2.84	757.02	485.27
1930	10.10	50.36	8.86	11.82	5.91	36.09	15.47	84.30	58.59	221.61	73.24	14.65	38.19	28.90	141.71	2.95	802.74	514.58
1935	-13.05	43.72	9.23	12.31	6.16	32.26	13.82	82.80	59.08	219.82	73.85	14.77	45.05	31.00	161.58	3.08	795.48	509.92
1940	-64.28	37.66	9.59	12.78	6.39	27.41	11.75	71.14	70.93	219.78	88.66	17.73	46.13	32.57	169.25	3.20	760.68	487.62
1945	-80.33	36.75	9.91	13.22	6.61	22.30	9.56	28.03	82.08	271.16	102.60	20.52	67.79	33.70	166.60	3.30	793.79	508.84
1950	-91.05	36.32	10.20	13.60	6.80	17.26	7.40	13.08	136.00	290.11	170.01	34.00	69.96	34.53	183.85	3.40	935.47	599.66
1955	-154.86	36.29	26.38	35.17	17.58	14.31	6.13	213.74	130.71	366.35	163.39	32.68	97.57	21.11	296.73	8.79	1312.07	841.07
1960	-157.49	35.06	26.88	35.84	17.92	13.61	5.83	210.88	128.54	343.09	160.67	32.13	99.98	18.57	321.14	8.96	1301.60	834.36
1965	-187.89	35.30	26.57	35.42	17.71	10.93	4.68	192.92	146.11	284.29	182.64	36.53	148.95	16.42	531.33	8.86	1490.76	955.62
1970	-149.00	35.80	25.94	34.58	17.29	9.50	4.07	114.46	166.70	280.79	208.38	41.68	154.03	17.18	567.15	8.65	1537.19	985.38
1975	-186.54	35.72	6.97	9.30	4.65	0.15	0.06	58.78	202.29	291.29	252.87	50.57	204.43	17.37	479.49	2.32	1429.72	916.49
1980	-149.63	37.27	4.11	5.48	2.74	-9.86	-4.23	35.44	288.48	209.52	360.60	72.12	243.06	17.48	493.66	1.37	1607.59	1030.51
1985	-122.33	32.97	3.39	4.52	2.26	-12.84	-5.50	25.77	357.93	82.73	447.41	89.48	287.27	15.84	856.40	1.13	2066.42	1324.63
1990	-109.94	31.15	1.18	1.57	0.78	-12.66	-5.42	20.11	375.68	61.10	469.60	93.92	295.12	18.59	916.93	0.39	2158.09	1383.39
1995	-109.94	28.32	1.18	1.57	0.78	-12.66	-5.42	20.11	444.35	31.08	555.44	111.09	376.03	18.59	706.49	0.39	2167.39	1389.35

GLOB* (Global*) = Proportionally calibrated for IGSM.

[1] For our purposes, we use this proportion for all regions, but since CO_2 is well-mixed the regional allocation is unimportant. We do not report those data here, because for other reasons, such as ascribing responsibility for past emissions, it would be important to correctly account for difference across regions.

2.2 Methane (CH_4) Emissions

Although the focus of this document is on anthropogenic emissions, in the case of CH_4, it is also important to compare and contrast with natural emissions.

2.2.1 Anthropogenic Methane (CH_4) Emissions

Historical emissions data for CH_4 was obtained from Van Aardenne *et al.* (2001), Olivier *et al.* (2001a), and Stern and Kaufmann (1998). The Van Aardenne *et al.* (2001) and Olivier *et al.* (2001a) data is essentially EDGAR (Emission Database for Global Atmospheric Research available at: http://www.mnp.nl/edgar) data spanning the time period 1890 to 1990 in which a regional aggregation is provided.

The estimates of anthropogenic methane emissions vary in different studies. The US EPA (2002, 2005) provides consistently lower numbers for global emissions for 1990-1995 than the EDGAR database. In contrast, the Stern and Kaufmann (1998) estimates of annual global emissions, spanning the years from 1860 to 1994, are higher. The Stern and Kaufmann (1998) global totals are more consistent with the methane emissions profile estimated via inverse methods (Chen, 2003). In order to compare and contrast, **Figure 1** presents the global totals from EDGAR and Stern and Kaufmann (1998), and the US EPA (2005). For **Table 6**, we have opted to report data based on the EDGAR source, though converted from the EDGAR format, where CH_4 is expressed in *mmt* of C-equivalent, into the EPPA format of *mmt* of CH_4.

2.2.2 Natural Methane (CH_4) Emissions

MIT's Natural Emissions Model (NEM) component is used to simulate historical and future emissions of methane (CH_4) from the terrestrial biosphere to the atmosphere. The natural

Table 6. CH_4 Emissions in Tg

YEAR	USA	CAN	MEX	JPN	ANZ	EUR	EET	FSU	ASI	CHN	IND	IDZ	AFR	MES	LAM	ROW	GLOBAL
1890	10.40	0.62	0.58	1.52	1.71	14.37	1.65	3.81	3.20	13.63	6.85	0.40	4.11	1.23	2.47	27.47	94.03
1895	11.59	0.68	0.63	1.62	1.61	17.77	1.75	4.21	3.34	13.97	7.06	0.41	4.10	1.18	2.68	28.28	100.87
1900	12.78	0.75	0.68	1.71	1.51	21.16	1.85	4.62	3.47	14.30	7.26	0.43	4.09	1.13	2.90	29.09	107.72
1905	14.89	0.83	0.88	1.88	1.75	21.88	2.11	4.76	3.82	14.81	7.20	0.47	4.42	1.18	3.75	28.85	113.47
1910	17.00	0.91	1.08	2.04	1.99	22.60	2.37	4.90	4.18	15.31	7.14	0.52	4.75	1.23	4.59	28.61	119.22
1915	19.06	0.99	1.16	2.30	2.15	22.05	2.64	5.61	4.85	15.99	7.52	0.60	5.46	1.29	4.93	30.13	126.72
1920	21.12	1.08	1.23	2.56	2.30	21.51	2.91	6.31	5.53	16.67	7.90	0.68	6.16	1.34	5.26	31.66	134.22
1925	20.49	1.14	1.39	2.25	2.38	23.22	3.72	7.02	7.20	19.06	7.29	0.89	7.00	1.65	5.92	29.22	139.85
1930	19.87	1.21	1.54	1.94	2.46	24.92	4.52	7.73	8.88	21.45	6.67	1.10	7.84	1.96	6.59	26.77	145.47
1935	20.20	1.28	1.58	2.73	2.55	25.71	4.67	8.68	8.22	21.36	7.45	1.02	7.95	2.16	6.73	29.86	152.13
1940	20.54	1.35	1.61	3.51	2.63	26.49	4.81	9.63	7.56	21.26	8.22	0.93	8.06	2.35	6.88	32.95	158.79
1945	22.07	1.46	1.83	3.22	2.82	26.13	5.61	10.69	7.80	22.05	8.25	0.96	11.80	2.74	7.79	33.08	168.31
1950	23.60	1.57	2.04	2.93	3.00	25.77	6.41	11.74	8.05	22.84	8.28	0.99	15.55	3.14	8.70	33.21	177.84
1955	24.21	1.73	2.86	3.27	3.38	27.02	7.48	15.26	9.46	32.27	8.66	1.17	14.68	3.93	12.19	34.75	202.32
1960	24.82	1.88	3.68	3.62	3.77	28.27	8.55	18.78	10.87	41.69	9.04	1.34	13.81	4.72	15.67	36.29	226.81
1965	27.70	2.13	4.11	3.50	4.35	27.57	9.41	22.30	11.78	41.61	9.09	1.46	16.25	5.91	17.50	36.49	241.15
1970	30.57	2.38	4.53	3.38	4.94	26.88	10.27	25.82	12.70	41.52	9.13	1.57	18.68	7.10	19.33	36.68	255.48
1975	32.14	2.55	5.07	2.99	5.20	26.70	11.53	29.33	13.88	45.05	9.43	1.71	20.70	8.05	21.60	37.87	273.80
1980	33.71	2.73	5.60	2.60	5.46	26.52	12.79	32.84	15.05	48.58	9.72	1.86	22.72	9.00	23.87	39.06	292.13
1985	37.48	3.26	5.86	2.62	5.69	25.00	11.76	39.78	15.76	48.43	9.86	1.95	24.33	9.56	24.97	39.60	305.90
1990	41.25	3.78	6.11	2.64	5.93	23.49	10.73	46.71	16.47	48.28	9.99	2.04	25.93	10.12	26.07	40.15	319.68
1995	45.03	4.31	6.37	2.66	6.16	21.97	9.70	53.64	17.18	48.13	10.12	2.12	27.53	10.68	27.16	40.69	333.45

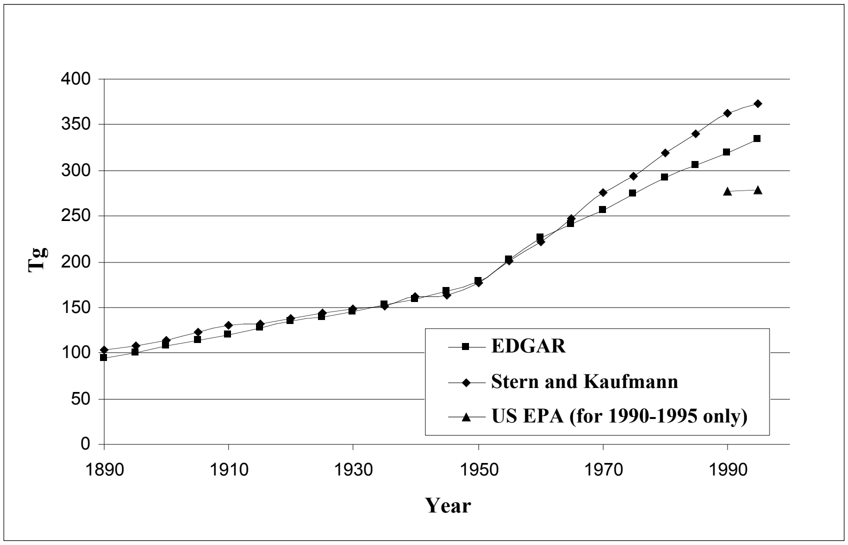

Figure 1. Comparison of Historical Global Totals of Anthropogenic CH_4 Emissions

terrestrial fluxes from soils and wetlands are important contributors to the global budgets for these gases. Because these fluxes are dependent on climate, global models to simulate the relevant biogeochemical processes are incorporated in the IGSM (Sokolov *et al.*, 2005). In addition to the fluxes from NEM, further emissions of 40 *Tg* are added in the post-processing step to represent emissions from termites, ocean, and other natural sources. Historical global totals of both anthropogenic and natural CH_4 emissions are illustrated in **Figure 2**. As can be seen in the figure, total natural emissions of methane range between 165 and 185 *Tg* yr^{-1} during the historical period, with an increase at the end of that period likely due to warmer climatic conditions. These emissions are consistent with literature estimates for natural emissions such as 190 ± 70 *Tg* yr^{-1} from Lelieveld *et al.* (1998).

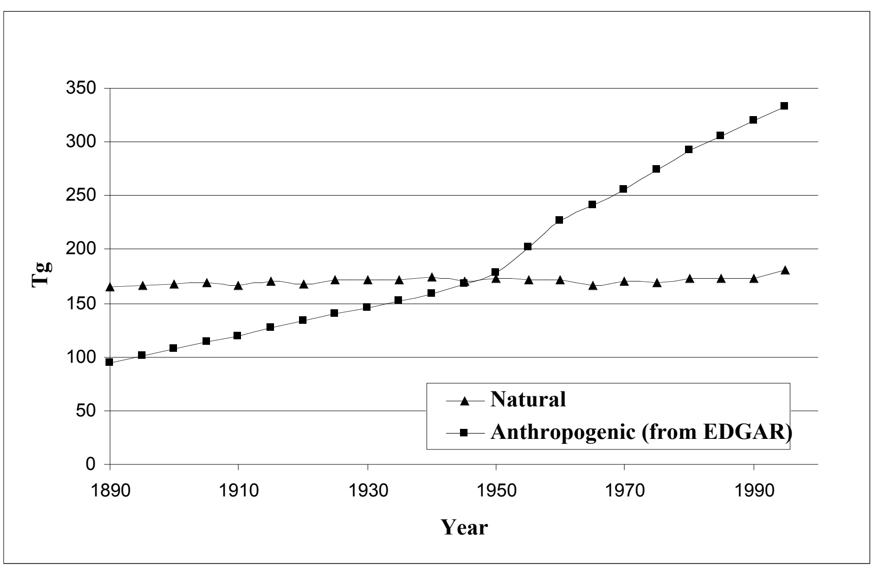

Figure 2. Historical Global Totals of Natural and Anthropogenic CH_4 Emissions

2.3 Nitrous Oxide (N_2O) Emissions

As with CH_4, we distinguish between natural and anthropogenic N_2O emissions in the following sub-sections.

2.3.1 Anthropogenic Nitrous Oxide (N_2O) Emissions

Historical emissions data for N_2O spanning the time period 1890 to 1990 was obtained from Van Aardenne *et al.* (2001) as well as Olivier *et al.* (2001a). These emissions data, in their original form, do not include emissions from combustion of biomass from forest clearing, forest fires, savannah burning, and the like. Thus, we approximated N_2O emissions from these sources by indexing the EPPA4 base year 1997 estimate for them to that of CO_2 emissions from land use change discussed in Section 2.1.3, on the assumption that combustion of biomass is closely related to trends in forest clearing and related activities that are also responsible for land use carbon emissions. Note that, in its initial form, N_2O is expressed in *mmt* of N, and was subsequently converted to *mmt* of N_2O. These data are in **Table 7**.

Table 7. N_2O Emissions in Tg

YEAR	USA	CAN	MEX	JPN	ANZ	EUR	EET	FSU	ASI	CHN	IND	IDZ	AFR	MES	LAM	ROW	GLOBAL
1890	0.24	0.08	0.07	0.07	0.12	0.19	0.08	0.17	0.08	0.13	0.46	0.06	0.15	0.09	0.10	0.06	2.15
1895	0.24	0.08	0.07	0.07	0.11	0.22	0.08	0.18	0.08	0.13	0.47	0.06	0.14	0.09	0.10	0.06	2.20
1900	0.25	0.08	0.07	0.07	0.11	0.26	0.08	0.18	0.08	0.13	0.47	0.06	0.14	0.09	0.10	0.06	2.25
1905	0.25	0.08	0.08	0.07	0.12	0.25	0.08	0.19	0.09	0.14	0.48	0.07	0.15	0.09	0.13	0.06	2.32
1910	0.26	0.08	0.08	0.07	0.12	0.23	0.08	0.19	0.09	0.14	0.49	0.07	0.17	0.09	0.16	0.06	2.39
1915	0.27	0.08	0.09	0.07	0.13	0.24	0.09	0.21	0.09	0.15	0.49	0.07	0.19	0.09	0.16	0.06	2.50
1920	0.28	0.08	0.09	0.07	0.13	0.24	0.10	0.24	0.10	0.16	0.50	0.07	0.21	0.09	0.17	0.06	2.60
1925	0.28	0.09	0.09	0.07	0.13	0.26	0.12	0.25	0.11	0.17	0.50	0.07	0.23	0.10	0.17	0.06	2.69
1930	0.27	0.09	0.09	0.07	0.14	0.27	0.13	0.25	0.11	0.18	0.51	0.07	0.25	0.11	0.17	0.06	2.78
1935	0.28	0.09	0.09	0.07	0.13	0.29	0.12	0.25	0.11	0.19	0.52	0.07	0.25	0.12	0.18	0.06	2.83
1940	0.29	0.09	0.09	0.08	0.13	0.31	0.11	0.24	0.12	0.20	0.52	0.07	0.25	0.12	0.20	0.06	2.88
1945	0.35	0.09	0.10	0.09	0.14	0.37	0.14	0.26	0.12	0.23	0.53	0.07	0.42	0.13	0.22	0.06	3.33
1950	0.41	0.09	0.10	0.11	0.14	0.44	0.18	0.29	0.13	0.26	0.55	0.07	0.59	0.14	0.24	0.07	3.79
1955	0.45	0.10	0.12	0.11	0.16	0.49	0.20	0.33	0.14	0.30	0.56	0.07	0.50	0.16	0.32	0.07	4.07
1960	0.48	0.11	0.14	0.12	0.17	0.54	0.22	0.38	0.14	0.34	0.58	0.07	0.41	0.17	0.40	0.07	4.35
1965	0.61	0.12	0.15	0.13	0.18	0.66	0.27	0.49	0.16	0.44	0.62	0.07	0.47	0.18	0.45	0.07	5.06
1970	0.73	0.13	0.16	0.14	0.19	0.78	0.32	0.59	0.17	0.53	0.67	0.08	0.53	0.19	0.50	0.07	5.77
1975	0.84	0.15	0.18	0.14	0.19	0.89	0.37	0.70	0.19	0.76	0.76	0.08	0.59	0.22	0.57	0.07	6.69
1980	0.94	0.17	0.20	0.14	0.19	1.00	0.42	0.82	0.22	1.00	0.85	0.08	0.64	0.24	0.64	0.07	7.61
1985	1.00	0.19	0.21	0.15	0.20	1.04	0.42	0.85	0.26	1.21	0.98	0.09	0.69	0.27	0.68	0.07	8.31
1990	1.05	0.20	0.22	0.16	0.21	1.08	0.42	0.88	0.30	1.43	1.12	0.09	0.75	0.30	0.72	0.07	9.00
1995	1.11	0.22	0.23	0.17	0.22	1.13	0.42	0.92	0.34	1.64	1.26	0.10	0.80	0.33	0.77	0.07	9.70

2.3.2 Natural Nitrous Oxide (N_2O) Emissions

Following the same source as indicated in Section 2.2.2, **Figure 3** illustrates the historical global totals of both anthropogenic and natural N_2O emissions.

2.4 Perfluorocarbon (PFC) Emissions

Historical emissions data for PFC compounds spanning the time period 1949/1950 to 1995 was obtained from Olivier and Bakker (2000) and Olivier *et al.* (2001b). Olivier and Bakker (2000) point out that PFC emissions (as well as other F-gases discussed in Sections 2.5 and 2.6) "…are being considered by policymakers with more attention since they are incorporated in the

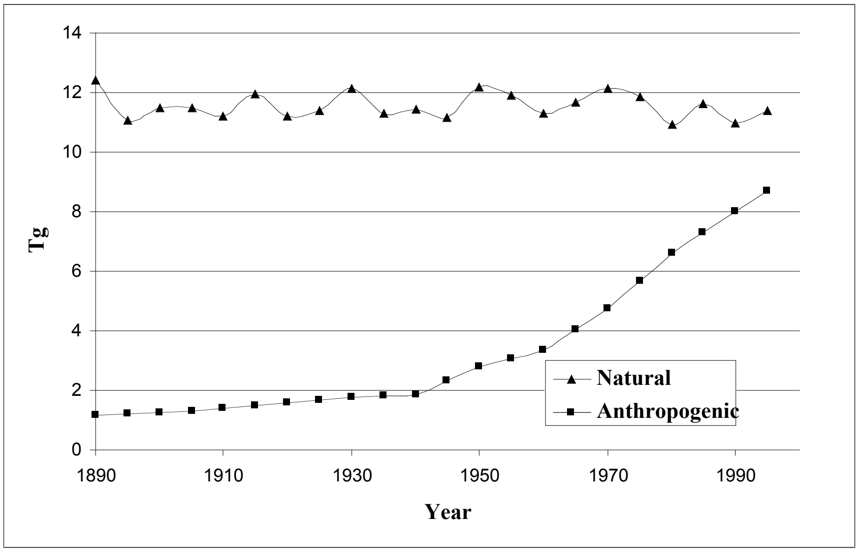

Figure 3. Historical Global Totals of Natural and Anthropogenic N_2O Emissions

greenhouse gas commitments of the Kyoto Protocol…" and that data on these emissions have only been compiled at the global level relatively recently from "…national statistics and available production or sales statistics of these compounds and emissions factors from recent literature…" (p. 1). The initial data consists of the following compounds: CF4, C2F6, C3F8, c-C4F10, C5F12, C6F14, and C7F16. Since EPPA utilizes PFC emissions in terms of CF4, all remaining compounds were translated using Global Warming Potentials (GWPs) reported in Ramaswamy *et al.* (2001). These data are in **Table 8**.

Table 8. PFC Emissions in Gg of CF4

YEAR	USA	CAN	MEX	JPN	ANZ	EUR	EET	FSU	ASI	CHN	IND	IDZ	AFR	MES	LAM	ROW	GLOBAL
1890	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1895	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1900	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1905	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1910	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1915	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1920	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1925	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1930	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1935	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1940	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1945	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1950	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1955	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1960	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1965	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1970	4.38	1.32	0.00	0.80	0.17	2.84	0.48	1.40	0.00	0.12	0.22	0.00	0.10	0.00	0.21	0.04	12.08
1975	3.10	1.20	0.00	1.11	0.25	3.77	0.82	2.00	0.00	0.26	0.25	0.00	0.13	0.21	0.32	0.09	13.51
1980	2.97	1.39	0.00	1.19	0.13	4.10	0.86	2.31	0.00	0.28	0.27	0.00	0.30	0.24	0.81	0.10	14.95
1985	2.26	1.34	0.00	0.34	0.20	3.56	0.96	2.76	0.00	0.31	0.39	0.04	0.37	0.35	0.92	0.11	13.92
1990	2.29	1.14	0.00	0.71	0.26	2.55	0.77	2.63	0.00	0.60	0.33	0.05	0.41	0.43	0.99	0.22	13.37
1995	3.50	1.27	0.00	2.49	0.27	2.33	0.47	3.61	0.00	1.30	0.38	0.11	0.24	0.18	0.60	0.48	17.22

2.5 Sulfur Hexafluoride (SF6) Emissions

Historical emissions data for SF6 spanning the time period 1949/1950 to 1995 was obtained from Olivier and Bakker (2000) and Olivier *et al.* (2001b). These data are in **Table 9**.

Table 9. SF6 Emissions in Gg

YEAR	USA	CAN	MEX	JPN	ANZ	EUR	EET	FSU	ASI	CHN	IND	IDZ	AFR	MES	LAM	ROW	GLOBAL
1890	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1895	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1900	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1905	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1910	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1915	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1920	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1925	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1930	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1935	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1940	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1945	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1950	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1955	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03
1960	0.12	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13
1965	0.47	0.05	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.55
1970	0.59	0.06	0.00	0.02	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.72
1975	0.88	0.09	0.00	0.04	0.00	0.16	0.00	0.00	0.02	0.06	0.05	0.01	0.03	0.10	0.01	0.00	1.46
1980	1.27	0.13	0.01	0.33	0.01	0.40	0.00	0.00	0.06	0.14	0.19	0.02	0.07	0.19	0.02	0.00	2.85
1985	1.58	0.16	0.02	0.37	0.02	0.57	0.00	0.00	0.10	0.22	0.25	0.02	0.11	0.28	0.05	0.00	3.77
1990	1.84	0.22	0.03	0.52	0.03	0.76	0.00	0.05	0.14	0.31	0.26	0.03	0.11	0.34	0.08	0.01	4.75
1995	2.18	0.26	0.03	0.77	0.04	1.01	0.01	0.35	0.10	0.61	0.22	0.02	0.10	0.25	0.06	0.01	6.00

2.6 Hydrofluorocarbon (HFC) Emissions

Historical emissions data for HFC compounds spanning the time period 1949/1950 to 1995 was obtained from Olivier and Bakker (2000) and Olivier *et al.* (2001b). The initial data consists of the following compounds: HFC-125, HFC-134a, HFC-143a, HFC-152a, HFC-227ea, and HFC-23. Since EPPA utilizes HFC emissions in terms of HFC-134a, all remaining compounds were translated using Global Warming Potentials (GWPs) reported in Ramaswamy *et al.* (2001).These data are in **Table 10**.

Table 10. HFC Emissions in Gg of HFC-134a

YEAR	USA	CAN	MEX	JPN	ANZ	EUR	EET	FSU	ASI	CHN	IND	IDZ	AFR	MES	LAM	ROW	GLOBAL
1890	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1895	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1900	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1905	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1910	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1915	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1920	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1925	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1930	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1935	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1940	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1945	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1950	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

YEAR	USA	CAN	MEX	JPN	ANZ	EUR	EET	FSU	ASI	CHN	IND	IDZ	AFR	MES	LAM	ROW	GLOBAL
1955	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1960	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1965	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1970	5.62	0.21	0.00	1.40	0.11	3.49	0.00	0.36	0.26	0.17	0.08	0.06	0.00	0.00	0.43	0.17	12.37
1975	7.90	0.30	0.00	1.97	0.16	4.90	0.00	0.51	0.37	0.24	0.11	0.08	0.00	0.00	0.60	0.24	17.39
1980	14.02	0.53	0.00	3.50	0.28	8.70	0.00	0.91	0.66	0.43	0.19	0.14	0.00	0.00	1.07	0.43	30.86
1985	18.00	0.67	0.00	4.50	0.36	11.17	0.00	1.16	0.84	0.56	0.25	0.19	0.00	0.00	1.37	0.56	39.62
1990	26.56	0.39	0.00	8.33	0.56	15.62	0.00	1.86	1.35	0.78	0.35	0.26	0.00	0.00	1.74	0.78	58.58
1995	44.83	1.27	0.00	13.57	1.32	27.58	0.99	3.96	1.71	0.97	0.43	0.32	0.43	0.10	2.47	0.97	100.91

2.7 Chlorofluorocarbon (CFC) Emissions

Historical CFC emissions, specifically CFC11 and CFC12 emissions, are based on the Global Emissions Inventory Activity (GEIA) data (McCulloch *et al.*, 2001; 2003). CFC11 and CFC12 annual global emissions data are available for years 1933 through 2000. Although CFC emissions are not projected by EPPA, global totals are included in EPPA's post-processor; they are assumed to decline to zero by year 2005. Hydrochlorofluorocarbons (HCFCs) are not included in the model at this time (Paltsev *et al.*, 2005). **Figure 4** illustrates these data for time periods consistent with other emissions species reported here.

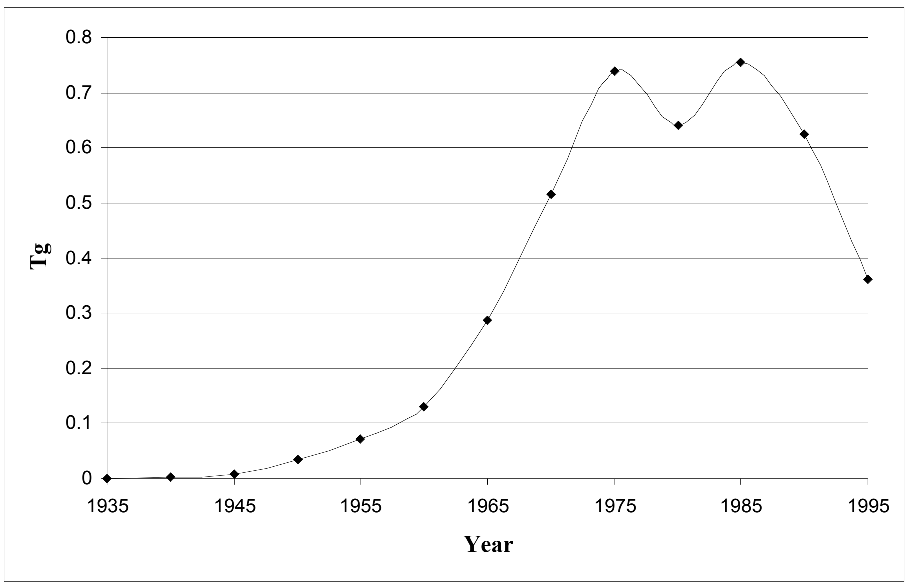

Figure 4. Historical Global Totals of CFC Emissions

3. HISTORICAL ANTHROPOGENIC EMISSIONS FOR OTHER CRITERIA POLLUTANTS

The criteria pollutants (SO_2, NO_X, CO, VOC, BC, OC, and NH_3) are important for the atmospheric chemistry of greenhouse gases, especially CH_4 due to its contribution to background O_3 in surface air, and being a greenhouse gas itself. Many of these substances also contribute to aerosol loading, some of which are cooling and others that contribute to warming. They are used as inputs to the IGSM and affect the strength of the source or sink terms in the trace gas budgets (Prinn *et al.*, 2005). As with GHG emissions, 1997 base year regional shares from the EPPA4 model were used to match the regional aggregation schemes for other criteria pollutants to those directly compatible with EPPA4. Again, there existed missing years in the historical data or they were reported at a periodicity different than the five-year time step of EPPA. In these cases, missing observations were interpolated using a cubic interpolation methodology where possible. The cubic interpolation method requires at least two observations on either side of the missing data point, and so linear interpolation was used in those few cases where the missing data was very near the end of the series. (Morton, 1964; Press *et al*., 1992).

3.1 Sulfur Dioxide (SO_2) Emissions

There exist a variety of sources for historical global SO_2 emissions. The most common are the EDGAR sources, namely Van Aardenne *et al.* (2001) and Olivier *et al.* (2001a), which covers the same time series of 1890 to 1990 as indicated previously. However, other researchers, such as Stern (2005), attempt to synthesize historical data sources to produce a continuous historical time series for most individual countries in the world spanning the years 1850 to 2000. The majority of the data Stern (2005) employs, consisting of years 1850 to 1990, was originally produced by ASL and Associates (1997) and Lefohn *et al.* (1999). According to Stern (2005), year 1995 data is from EDGAR 3.0 and remaining years originate from "actual observed data", interpolation/extrapolation, and/or econometric estimation. A third major source of historical global SO_2 emissions is Smith *et al.* (2004). There, global and regional SO_2 emissions are available for years 1850 to 2000. It is stated that the "inventory was constructed by using a combination of bottom-up calculations and Best Available Inventories (BAI)" (p. 2). **Figure 5** provides a comparison and contrast of the global historical totals for each of these three major data sources.

Although, the general trend for Stern (2005) and Smith *et al.* (2004) is similar, all three sources vary most from years 1990 to 2000. Specifically, EDGAR 3.0 emissions are largely underestimated as compared to Stern (2005) and Smith *et al.* (2004) for years prior to 1990.

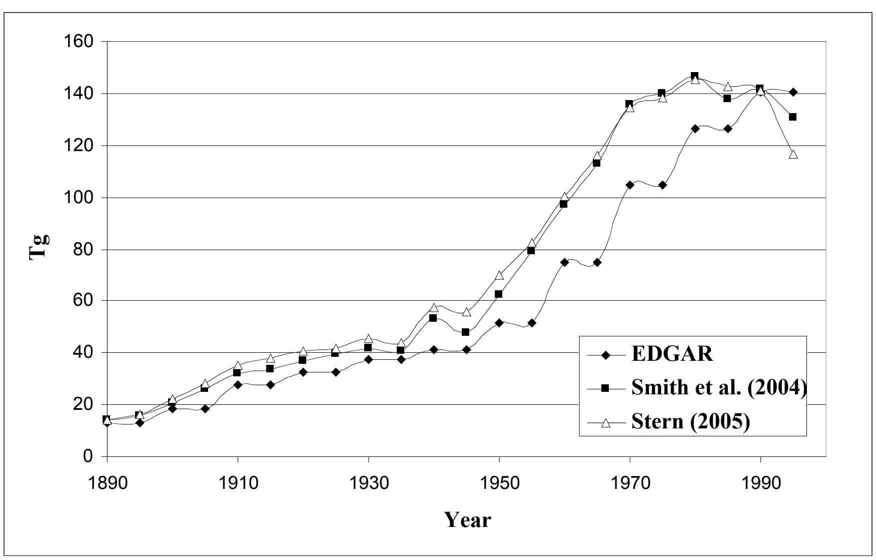

Figure 5. Comparison of Historical Global SO_2 Totals

During the 1990s, Smith *et al.* (2004) point out that "Changes in fossil fuel use, increases in the amount of sulfur removals from oil and non-ferrous metals, and controls on coal-fired power plants have contributed to this decline (in SO_2 emissions)" (p. 7). Quantitatively speaking, the EDGAR 3.0 data does not capture this effect. See Smith *et al.* (2004) for a more extensive comparison to several other published estimates of SO_2 emissions for the same time period, with the exception of Stern (2005). In short, we believe that the relatively large decline in SO_2 emissions during the 1990s is most consistent with observation as well as the future time trend emissions coefficients in EPPA4 (Sarofim *et al.,* 2006). Note that, in its initial form, SO_2 is expressed in *mmt* of S, and was subsequently converted to *mmt* of SO_2. These data are in **Table 11**. In addition, 26 *Tg* of SO_2 from marine and terrestrial biospheres (Spiro *et al.*, 1992) is also added in the post-processor, where emissions are distributed latitudinally throughout.

Table 11. SO_2 Emissions in Tg

YEAR	USA	CAN	MEX	JPN	ANZ	EUR	EET	FSU	ASI	CHN	IND	IDZ	AFR	MES	LAM	ROW	GLOBAL
1890	5.67	0.32	0.18	0.14	0.25	3.77	0.47	0.41	0.18	0.57	0.43	0.08	0.81	0.13	0.53	0.08	14.00
1895	5.79	0.44	0.30	0.26	0.37	3.90	0.59	0.54	0.31	0.70	0.55	0.21	0.93	0.25	0.65	0.20	16.00
1900	8.49	0.48	0.27	0.22	0.35	5.61	0.71	0.65	0.28	0.81	0.55	0.14	0.98	0.19	0.75	0.13	20.60
1905	8.82	0.82	0.60	0.56	0.68	5.94	1.05	0.99	0.62	1.15	0.89	0.48	1.32	0.53	1.09	0.46	26.00
1910	12.95	0.83	0.49	0.44	0.59	8.59	1.18	1.09	0.51	1.26	0.82	0.31	1.33	0.37	1.15	0.29	32.20
1915	13.04	0.92	0.57	0.53	0.67	8.68	1.27	1.17	0.60	1.34	0.91	0.40	1.42	0.46	1.24	0.38	33.60
1920	15.05	0.93	0.54	0.48	0.64	10.11	1.33	1.25	0.57	1.40	0.89	0.33	1.47	0.40	1.33	0.30	37.00
1925	15.20	1.08	0.69	0.63	0.79	10.26	1.48	1.40	0.72	1.55	1.04	0.48	1.62	0.55	1.48	0.45	39.40
1930	15.24	1.03	0.59	0.51	0.63	12.32	1.67	2.30	0.68	1.58	0.94	0.32	1.68	0.41	1.61	0.28	41.80
1935	15.16	0.96	0.51	0.43	0.56	12.25	1.59	2.23	0.61	1.51	0.86	0.25	1.60	0.33	1.54	0.21	40.60
1940	13.49	1.51	1.15	1.10	1.20	13.76	2.49	5.58	1.27	2.48	1.56	0.80	2.56	1.02	2.48	0.75	53.20
1945	13.14	1.16	0.80	0.75	0.85	13.41	2.14	5.23	0.92	2.13	1.21	0.45	2.21	0.67	2.13	0.40	47.60
1950	18.78	1.89	1.13	0.97	1.24	13.02	3.83	7.68	1.18	2.89	1.62	0.73	2.86	1.04	2.65	0.68	62.20
1955	19.85	2.96	2.21	2.05	2.32	14.09	4.91	8.75	2.26	3.96	2.70	1.81	3.94	2.11	3.73	1.76	79.40
1960	18.80	2.49	2.17	2.03	2.22	17.95	7.32	14.64	2.37	10.07	2.86	1.51	4.55	2.08	4.72	1.41	97.20
1965	19.79	3.47	3.16	3.02	3.20	18.94	8.31	15.62	3.36	11.06	3.85	2.50	5.54	3.07	5.71	2.40	113.00
1970	24.67	3.66	3.17	4.05	3.08	26.35	7.28	20.75	3.73	14.01	3.92	2.17	6.00	3.83	7.15	1.98	135.80
1975	24.92	3.91	3.42	4.30	3.33	26.60	7.53	21.00	3.98	14.26	4.17	2.42	6.25	4.08	7.40	2.23	139.80
1980	26.05	3.36	2.82	3.33	2.67	23.28	8.48	27.60	4.32	18.61	3.97	1.64	6.56	4.50	7.91	1.30	146.40
1985	25.53	2.83	2.30	2.80	2.15	22.76	7.95	27.07	3.80	18.09	3.44	1.11	6.04	3.98	7.38	0.78	138.00
1990	21.70	2.41	1.78	1.83	1.63	21.82	10.83	22.84	4.51	27.80	4.78	0.62	6.86	4.71	7.35	0.12	141.60
1995	19.78	1.73	1.09	1.15	0.94	21.13	10.14	22.15	3.82	27.11	4.09	0.55	6.18	4.02	6.67	0.05	130.60

3.2 Nitrogen Oxide (NO_X) Emissions

Historical emissions data for NO_x spanning the time period 1890 to 1990 was obtained from Van Aardenne *et al.* (2001) as well as Olivier *et al.* (2001a). Since these emissions data, in their original form, do not include emissions from biomass, emissions for this component of NO_X were indexed to EPPA4 base year 1997 CO_2 emissions from land use change as was done for N_2O emissions in Section 2.3.1. Note that, in its initial form, NO_X is expressed in *mmt* of N, and was subsequently converted to *mmt* of NO_2. Although there exists a variety of substances in which to report these emissions, we have opted to report them in terms of NO_2 for **Table 12** in order to maintain consistency with the IGSM. Moreover, an additional 21 *Tg* of NO_x are added post-process to account for lightning and other natural sources.

Table 12. NO_X Emissions in Tg of NO_2

YEAR	USA	CAN	MEX	JPN	ANZ	EUR	EET	FSU	ASI	CHN	IND	IDZ	AFR	MES	LAM	ROW	GLOBAL
1890	2.97	0.36	1.01	0.12	1.41	2.24	0.34	1.10	0.73	1.89	1.96	0.09	5.94	0.62	4.30	0.04	25.09
1895	3.42	0.39	1.05	0.14	1.43	2.50	0.38	1.14	0.76	1.92	2.00	0.09	6.05	0.62	4.46	0.04	26.40
1900	3.87	0.42	1.08	0.16	1.45	2.76	0.41	1.18	0.79	1.95	2.05	0.10	6.17	0.63	4.62	0.04	27.70
1905	4.58	0.46	1.13	0.20	1.48	3.18	0.46	1.23	0.82	1.99	2.11	0.10	6.34	0.65	4.81	0.05	29.59
1910	5.29	0.50	1.17	0.24	1.51	3.60	0.52	1.28	0.86	2.04	2.17	0.11	6.52	0.66	4.99	0.05	31.49
1915	5.90	0.53	1.22	0.26	1.53	3.81	0.54	1.32	0.89	2.07	2.22	0.11	6.71	0.68	5.20	0.05	33.04
1920	6.50	0.56	1.27	0.27	1.55	4.02	0.56	1.36	0.93	2.11	2.26	0.12	6.91	0.69	5.42	0.05	34.59
1925	7.21	0.60	1.32	0.31	1.56	4.35	0.62	1.53	0.98	2.15	2.33	0.12	7.13	0.72	5.64	0.05	36.62
1930	7.92	0.65	1.37	0.34	1.57	4.67	0.68	1.70	1.03	2.18	2.40	0.13	7.35	0.74	5.86	0.05	38.65
1935	8.05	0.67	1.41	0.43	1.61	4.85	0.74	2.17	1.07	2.24	2.52	0.13	7.65	0.80	6.02	0.05	40.41
1940	8.18	0.69	1.45	0.52	1.65	5.03	0.80	2.63	1.11	2.30	2.63	0.14	7.95	0.86	6.18	0.05	42.18
1945	10.27	0.82	1.48	0.49	1.73	5.08	1.14	3.11	1.18	2.38	2.76	0.15	8.56	0.92	6.32	0.05	46.43
1950	12.36	0.94	1.51	0.46	1.80	5.13	1.49	3.59	1.24	2.46	2.89	0.15	9.16	0.98	6.45	0.06	50.67
1955	13.93	1.07	1.66	0.76	1.93	6.21	2.13	4.85	1.39	3.25	3.20	0.17	9.82	1.15	7.06	0.06	58.62
1960	15.50	1.19	1.80	1.07	2.06	7.28	2.76	6.11	1.54	4.04	3.50	0.19	10.47	1.32	7.67	0.06	66.56
1965	18.12	1.47	1.91	1.54	2.21	9.74	2.82	7.47	1.78	4.68	3.91	0.22	11.79	1.63	8.15	0.07	77.53
1970	20.74	1.75	2.03	2.01	2.37	12.20	2.87	8.83	2.03	5.33	4.31	0.25	13.11	1.95	8.63	0.07	88.49
1975	23.12	2.07	2.23	2.25	2.60	13.38	3.33	10.68	2.40	6.84	4.87	0.30	14.52	2.53	9.49	0.08	100.70
1980	25.49	2.40	2.43	2.50	2.84	14.56	3.79	12.53	2.77	8.36	5.43	0.34	15.93	3.10	10.35	0.09	112.90
1985	26.39	2.38	2.52	2.75	3.05	14.85	3.41	12.87	3.44	10.38	6.50	0.42	17.52	3.58	10.74	0.09	120.89
1990	27.28	2.36	2.61	2.99	3.26	15.15	3.03	13.21	4.10	12.41	7.58	0.51	19.10	4.06	11.12	0.10	128.89
1995	28.18	2.34	2.70	3.24	3.47	15.45	2.65	13.56	4.77	14.44	8.66	0.59	20.69	4.54	11.51	0.11	136.88

3.3 Carbon Monoxide (CO) Emissions

Historical emissions data for CO spanning the time period 1890 to 1990 was obtained from Van Aardenne *et al.* (2001) as well as Olivier *et al.* (2001a). Again, since these emissions data, in their original form, do not include emissions from biomass, CO emissions were indexed to EPPA4 base year 1997 CO_2 emissions from land use change. Note that, in its initial form, CO is expressed in *mmt* of C, and was subsequently converted to *mmt* of CO. These data are in **Table 13**. An additional 370 *Tg* of CO from oceans (20 *Tg*) and vegetation (350 *Tg*) are added by the post-processor.

Table 13. CO Emissions in Tg

YEAR	USA	CAN	MEX	JPN	ANZ	EUR	EET	FSU	ASI	CHN	IND	IDZ	AFR	MES	LAM	ROW	GLOBAL
1890	19.45	3.19	7.39	0.41	6.80	29.56	5.60	13.45	10.67	48.30	50.97	1.32	60.96	8.28	31.50	0.21	298.06
1895	21.37	3.47	8.96	0.51	7.96	31.26	5.91	14.36	11.57	49.31	52.34	1.43	65.75	8.50	38.18	0.25	321.13
1900	23.28	3.74	10.52	0.61	9.12	32.96	6.22	15.28	12.47	50.32	53.72	1.54	70.55	8.73	44.86	0.28	344.20
1905	25.69	4.03	11.53	0.77	9.39	35.42	6.69	16.34	13.54	51.62	55.18	1.67	73.68	9.13	49.15	0.29	364.12
1910	28.10	4.32	12.53	0.93	9.66	37.87	7.16	17.40	14.60	52.93	56.64	1.80	76.81	9.54	53.43	0.30	384.04
1915	31.58	4.60	13.65	1.01	9.90	38.98	7.36	18.32	15.75	54.06	58.01	1.95	80.81	9.93	58.18	0.31	404.40
1920	35.06	4.88	14.76	1.10	10.14	40.08	7.55	19.23	16.90	55.20	59.38	2.09	84.80	10.33	62.93	0.31	424.75
1925	40.23	5.25	15.89	1.25	10.42	42.47	8.02	20.95	18.25	56.16	61.31	2.26	89.60	10.98	67.75	0.32	451.10
1930	45.39	5.62	17.03	1.40	10.69	44.86	8.48	22.66	19.60	57.12	63.23	2.42	94.39	11.64	72.58	0.33	477.45
1935	47.66	5.84	17.87	1.64	11.03	45.28	8.84	25.67	21.23	58.54	66.09	2.62	100.17	12.83	76.20	0.34	501.87
1940	49.94	6.07	18.72	1.89	11.37	45.70	9.21	28.69	22.87	59.96	68.95	2.83	105.94	14.01	79.81	0.35	526.30
1945	57.34	6.52	19.21	2.01	11.83	44.90	11.16	31.59	24.16	61.79	71.77	2.99	112.59	15.12	81.87	0.37	555.20
1950	64.73	6.98	19.69	2.13	12.29	44.11	13.11	34.49	25.45	63.61	74.59	3.15	119.24	16.23	83.94	0.38	584.11
1955	71.96	7.94	21.15	3.34	13.42	49.01	16.35	40.25	28.34	76.83	80.40	3.50	128.73	18.39	90.15	0.41	650.18
1960	79.20	8.91	22.60	4.55	14.54	53.92	19.59	46.01	31.23	90.04	86.22	3.86	138.22	20.56	96.36	0.45	716.24
1965	84.20	9.59	23.89	6.40	15.41	57.29	18.24	50.21	34.08	100.31	92.85	4.21	148.91	22.13	101.83	0.48	770.03

YEAR	USA	CAN	MEX	JPN	ANZ	EUR	EET	FSU	ASI	CHN	IND	IDZ	AFR	MES	LAM	ROW	GLOBAL
1970	89.19	10.27	25.17	8.25	16.28	60.66	16.89	54.41	36.94	110.58	99.49	4.57	159.60	23.71	107.29	0.50	823.82
1975	92.39	11.32	26.90	9.25	17.27	63.89	19.02	60.60	41.07	109.82	104.97	5.08	177.76	26.42	114.66	0.53	880.93
1980	95.58	12.38	28.62	10.24	18.26	67.12	21.14	66.78	45.21	109.05	110.45	5.59	195.91	29.13	122.03	0.56	938.05
1985	98.23	12.09	29.19	11.34	19.48	69.83	19.55	68.07	49.46	118.00	117.21	6.11	216.11	32.29	124.43	0.60	991.98
1990	100.88	11.81	29.75	12.44	20.71	72.54	17.95	69.36	53.71	126.95	123.96	6.64	236.30	35.45	126.82	0.64	1045.91
1995	103.52	11.52	30.31	13.55	21.93	75.25	16.36	70.64	57.97	135.91	130.72	7.16	256.49	38.61	129.22	0.68	1099.84

3.4 Volatile Organic Compound (VOC) Emissions

Historical emissions data for Non-Methane (NM) VOC spanning the time period 1890 to 1990 was obtained from Van Aardenne *et al.* (2001) as well as Olivier *et al.* (2001a). These data are in **Table 14**.

Table 14. VOC Emissions in Tg

YEAR	USA	CAN	MEX	JPN	ANZ	EUR	EET	FSU	ASI	CHN	IND	IDZ	AFR	MES	LAM	ROW	GLOBAL
1890	1.77	0.23	0.61	0.13	0.56	2.48	0.48	1.02	1.10	5.79	5.10	0.14	4.06	0.81	2.58	0.02	26.87
1895	2.11	0.26	0.74	0.19	0.66	2.79	0.52	1.17	1.22	5.94	5.31	0.15	4.34	0.84	3.14	0.02	29.41
1900	2.45	0.29	0.87	0.25	0.75	3.10	0.57	1.31	1.34	6.09	5.53	0.17	4.63	0.87	3.71	0.02	31.94
1905	2.80	0.32	0.96	0.28	0.78	3.40	0.62	1.41	1.47	6.23	5.73	0.18	5.01	0.91	4.07	0.02	34.20
1910	3.16	0.35	1.04	0.32	0.81	3.71	0.67	1.51	1.59	6.37	5.92	0.20	5.40	0.95	4.44	0.02	36.45
1915	3.73	0.37	1.16	0.36	0.83	3.90	0.70	1.58	1.73	6.52	6.11	0.21	5.87	1.00	4.93	0.03	39.02
1920	4.30	0.40	1.27	0.40	0.85	4.09	0.72	1.65	1.87	6.67	6.30	0.23	6.33	1.05	5.42	0.03	41.58
1925	5.25	0.46	1.38	0.45	0.89	4.41	0.79	1.85	2.04	6.79	6.54	0.25	6.85	1.13	5.88	0.03	45.00
1930	6.21	0.51	1.49	0.50	0.92	4.73	0.87	2.04	2.21	6.91	6.78	0.27	7.38	1.22	6.34	0.03	48.42
1935	6.94	0.56	1.58	0.60	0.97	4.93	0.92	2.35	2.42	7.06	7.10	0.30	8.02	1.36	6.72	0.03	51.86
1940	7.67	0.60	1.67	0.69	1.02	5.12	0.97	2.67	2.62	7.22	7.43	0.32	8.67	1.50	7.11	0.03	55.30
1945	9.24	0.71	1.77	0.72	1.08	5.38	1.14	2.99	2.82	7.40	7.78	0.35	9.45	1.95	7.55	0.03	60.38
1950	10.81	0.83	1.88	0.76	1.15	5.64	1.31	3.31	3.02	7.59	8.12	0.37	10.23	2.40	8.00	0.04	65.47
1955	12.73	1.16	2.14	1.19	1.33	7.32	1.76	4.45	3.54	8.65	9.07	0.44	11.60	3.35	9.11	0.04	77.87
1960	14.65	1.49	2.40	1.63	1.50	9.01	2.20	5.58	4.05	9.70	10.01	0.50	12.97	4.30	10.22	0.05	90.26
1965	16.97	1.88	2.66	2.66	1.68	10.88	2.32	7.78	4.77	11.30	11.19	0.59	15.54	6.18	11.33	0.05	107.77
1970	19.30	2.26	2.92	3.68	1.86	12.76	2.43	9.97	5.48	12.90	12.37	0.68	18.10	8.06	12.43	0.06	125.28
1975	20.87	2.62	3.22	4.56	2.08	15.07	2.93	12.45	6.54	14.41	13.57	0.81	20.24	9.49	13.74	0.06	142.66
1980	22.44	2.97	3.53	5.44	2.30	17.38	3.43	14.93	7.59	15.91	14.76	0.94	22.39	10.91	15.04	0.07	160.04
1985	23.32	3.15	3.73	6.40	2.55	19.25	3.54	16.83	8.89	17.81	16.53	1.10	25.26	11.62	15.88	0.08	175.94
1990	24.20	3.33	3.92	7.35	2.80	21.12	3.65	18.73	10.20	19.71	18.30	1.26	28.12	12.33	16.72	0.09	191.83
1995	25.09	3.51	4.12	8.30	3.05	22.99	3.76	20.62	11.50	21.60	20.07	1.42	30.99	13.05	17.57	0.09	207.73

3.5 Black Carbon (BC) Emissions

Novakov *et al.* (2003) provide global and regional historical fossil fuel BC emissions data spanning the time period 1875 to 2000. They "…estimate past BC emissions from annual consumption data for the principal BC-producing fossil-fuels and BC emission factors segregated by utilization sectors: industrial, residential/commercial, and electric power generation for coal, and transportation for diesel fuel" (p. 1). In addition, spatial and temporal voids in global and, especially, regional BC emissions from fossil fuels were extrapolated "…by assuming fossil fuel BC emissions were proportional to fossil fuel CO_2 emissions in that period" (p. 3). In order to obtain total BC emissions from both fossil fuel as well as biomass sources, we indexed these fossil fuel regional BC emissions to EPPA4 base year 1997 CO_2 emissions from land use change. These data are in **Table 15**.

Table 15. BC Emissions in Tg

YEAR	USA	CAN	MEX	JPN	ANZ	EUR	EET	FSU	ASI	CHN	IND	IDZ	AFR	MES	LAM	ROW	GLOBAL
1890	0.68	0.05	0.10	0.05	0.04	0.59	0.07	0.04	0.08	0.04	0.04	0.07	0.06	0.10	0.06	0.06	2.13
1895	0.83	0.05	0.12	0.05	0.05	0.61	0.08	0.04	0.10	0.04	0.04	0.08	0.08	0.12	0.07	0.08	2.46
1900	1.34	0.08	0.18	0.08	0.08	0.71	0.12	0.07	0.15	0.07	0.07	0.13	0.12	0.18	0.10	0.12	3.58
1905	1.58	0.08	0.18	0.08	0.07	0.73	0.12	0.07	0.15	0.07	0.07	0.13	0.11	0.18	0.10	0.11	3.85
1910	1.97	0.10	0.22	0.10	0.09	0.79	0.15	0.08	0.18	0.08	0.08	0.15	0.14	0.22	0.12	0.14	4.63
1915	2.18	0.10	0.22	0.10	0.09	0.80	0.14	0.08	0.18	0.08	0.08	0.15	0.14	0.22	0.12	0.14	4.80
1920	2.44	0.09	0.20	0.09	0.08	0.77	0.13	0.07	0.16	0.07	0.07	0.14	0.13	0.20	0.11	0.13	4.89
1925	2.43	0.11	0.23	0.11	0.10	0.73	0.16	0.09	0.19	0.01	0.09	0.16	0.15	0.24	0.13	0.15	5.07
1930	2.16	0.12	0.26	0.12	0.12	0.72	0.18	0.10	0.22	0.06	0.03	0.18	0.17	0.26	0.15	0.17	5.03
1935	1.99	0.14	0.30	0.14	0.13	0.70	0.20	0.12	0.25	0.10	0.07	0.21	0.19	0.30	0.17	0.19	5.21
1940	2.18	0.18	0.36	0.17	0.16	0.78	0.24	0.17	0.30	0.15	0.12	0.25	0.23	0.36	0.21	0.23	6.10
1945	2.70	0.11	0.21	0.10	0.10	0.68	0.15	0.43	0.18	0.19	0.16	0.15	0.14	0.22	0.13	0.14	5.80
1950	1.84	0.09	0.17	0.08	0.08	0.87	0.12	0.69	0.14	0.24	0.21	0.12	0.11	0.17	0.10	0.11	5.15
1955	1.37	0.10	0.20	0.10	0.09	0.96	0.13	1.03	0.16	0.37	0.25	0.14	0.13	0.20	0.12	0.13	5.47
1960	1.10	0.13	0.27	0.13	0.12	1.03	0.19	1.16	0.23	1.62	0.37	0.19	0.18	0.27	0.16	0.18	7.34
1965	1.04	0.15	0.29	0.14	0.13	0.89	0.20	1.24	0.25	0.94	0.53	0.21	0.19	0.30	0.17	0.19	6.87
1970	0.99	0.20	0.40	0.19	0.18	0.97	0.27	1.27	0.33	1.41	0.52	0.28	0.26	0.40	0.24	0.26	8.17
1975	0.86	0.26	0.52	0.25	0.24	0.77	0.35	2.09	0.43	2.10	0.63	0.37	0.34	0.52	0.31	0.34	10.36
1980	0.74	0.30	0.61	0.30	0.28	0.76	0.42	2.30	0.51	2.81	0.77	0.44	0.40	0.62	0.36	0.40	12.03
1985	0.54	0.31	0.64	0.31	0.29	0.87	0.44	2.30	0.53	3.67	1.12	0.45	0.42	0.64	0.38	0.42	13.33
1990	0.61	0.38	0.78	0.38	0.36	0.78	0.53	2.30	0.65	4.34	1.23	0.55	0.51	0.78	0.46	0.51	15.17
1995	0.63	0.33	0.66	0.32	0.30	0.51	0.46	0.83	0.55	4.93	1.48	0.47	0.44	0.67	0.40	0.44	13.43

3.6 Organic Carbon (OC) Emissions

It is relatively difficult to obtain a historical time series of OC emissions. Thus, we opted to utilize published OC/BC ratios for most countries and regions in the world in conjunction with the data in Table 12 in order to generate a historical time series of OC emissions. Regional OC/BC ratios are readily available from the seminal contribution of Bond *et al.* (2004). Most recently, Novakov *et al.* (2005) also provides a comparison of such regional OC/BC ratios across the published literature as well as its own calculations. The one caveat is that these ratios are time invariant. These data are in **Table 16**.

Table 16. OC in Tg

YEAR	USA	CAN	MEX	JPN	ANZ	EUR	EET	FSU	ASI	CHN	IND	IDZ	AFR	MES	LAM	ROW	GLOBAL
1890	2.33	0.16	0.42	0.06	0.08	1.41	0.16	0.09	0.28	0.09	0.12	0.39	0.90	0.43	0.19	0.27	7.36
1895	2.83	0.19	0.50	0.07	0.09	1.47	0.19	0.11	0.33	0.10	0.14	0.46	1.06	0.50	0.22	0.31	8.58
1900	4.54	0.28	0.75	0.10	0.14	1.72	0.29	0.16	0.49	0.16	0.22	0.69	1.60	0.76	0.33	0.47	12.71
1905	5.39	0.28	0.75	0.10	0.14	1.77	0.29	0.16	0.49	0.16	0.21	0.69	1.60	0.76	0.33	0.47	13.58
1910	6.71	0.34	0.92	0.13	0.17	1.90	0.35	0.19	0.60	0.19	0.26	0.84	1.95	0.92	0.40	0.58	16.46
1915	7.40	0.33	0.90	0.12	0.17	1.94	0.34	0.19	0.59	0.19	0.26	0.82	1.90	0.90	0.39	0.56	17.00
1920	8.28	0.31	0.83	0.11	0.16	1.86	0.32	0.18	0.54	0.17	0.24	0.75	1.75	0.83	0.36	0.52	17.20
1925	8.27	0.37	0.96	0.14	0.19	1.76	0.37	0.21	0.63	0.03	0.29	0.89	2.07	0.97	0.43	0.61	18.18
1930	7.35	0.42	1.08	0.16	0.22	1.74	0.43	0.25	0.71	0.13	0.10	1.01	2.35	1.08	0.49	0.70	18.22
1935	6.77	0.48	1.22	0.18	0.25	1.69	0.48	0.28	0.81	0.24	0.24	1.15	2.68	1.23	0.56	0.79	19.07
1940	7.41	0.60	1.46	0.22	0.31	1.88	0.59	0.41	0.98	0.34	0.39	1.39	3.26	1.47	0.69	0.96	22.37
1945	9.18	0.36	0.88	0.14	0.19	1.64	0.35	1.04	0.59	0.45	0.53	0.84	1.97	0.89	0.41	0.58	20.04
1950	6.27	0.29	0.71	0.11	0.15	2.09	0.29	1.66	0.47	0.56	0.68	0.67	1.58	0.71	0.33	0.47	17.04
1955	4.67	0.33	0.81	0.12	0.17	2.31	0.32	2.48	0.54	0.86	0.82	0.77	1.80	0.81	0.38	0.53	17.73
1960	3.75	0.45	1.11	0.17	0.23	2.49	0.45	2.80	0.74	3.82	1.21	1.05	2.47	1.12	0.52	0.73	23.12
1965	3.54	0.49	1.21	0.19	0.25	2.15	0.49	2.99	0.81	2.20	1.71	1.15	2.69	1.22	0.57	0.80	22.46
1970	3.37	0.67	1.63	0.25	0.34	2.34	0.65	3.05	1.09	3.32	1.69	1.55	3.63	1.64	0.77	1.07	27.05

YEAR	USA	CAN	MEX	JPN	ANZ	EUR	EET	FSU	ASI	CHN	IND	IDZ	AFR	MES	LAM	ROW	GLOBAL
1975	2.91	0.87	2.13	0.33	0.45	1.85	0.85	5.04	1.42	4.93	2.03	2.02	4.74	2.14	1.00	1.40	34.10
1980	2.52	1.03	2.52	0.39	0.53	1.83	1.01	5.53	1.68	6.61	2.49	2.39	5.62	2.54	1.19	1.66	39.54
1985	1.85	1.07	2.62	0.40	0.55	2.10	1.05	5.53	1.75	8.62	3.65	2.48	5.83	2.63	1.23	1.72	43.09
1990	2.07	1.31	3.20	0.49	0.68	1.88	1.29	5.53	2.14	10.20	3.99	3.04	7.14	3.22	1.51	2.11	49.80
1995	2.13	1.12	2.73	0.42	0.58	1.23	1.10	2.01	1.82	11.58	4.82	2.59	6.09	2.75	1.28	1.80	44.05

3.7 Ammonia (NH_3) Emissions

Historical emissions data for NH_3 spanning the time period 1890 to 1990 was obtained from Van Aardenne *et al.* (2001) as well as Olivier *et al.* (2001a). Note that, in its initial form, NH_3 is expressed in *mmt* of N, and was subsequently converted to *mmt* of NH_3. These data are in **Table 17**.

Table 17. NH_3 in Tg

YEAR	USA	CAN	MEX	JPN	ANZ	EUR	EET	FSU	ASI	CHN	IND	IDZ	AFR	MES	LAM	ROW	GLOBAL
1890	0.92	0.08	0.07	0.03	0.20	0.64	0.11	0.55	0.11	0.43	1.99	0.01	0.39	0.10	0.30	0.01	5.95
1895	0.95	0.09	0.08	0.04	0.19	0.83	0.10	0.58	0.12	0.45	2.01	0.01	0.42	0.10	0.35	0.01	6.33
1900	0.98	0.10	0.09	0.04	0.18	1.02	0.08	0.62	0.13	0.47	2.04	0.02	0.45	0.11	0.40	0.01	6.72
1905	1.01	0.10	0.12	0.04	0.21	0.94	0.09	0.63	0.14	0.49	2.08	0.02	0.49	0.11	0.51	0.01	6.98
1910	1.03	0.11	0.15	0.04	0.24	0.86	0.09	0.64	0.16	0.51	2.11	0.02	0.53	0.12	0.63	0.01	7.25
1915	1.10	0.12	0.16	0.04	0.25	0.89	0.14	0.75	0.19	0.55	2.14	0.02	0.64	0.12	0.68	0.01	7.83
1920	1.18	0.13	0.17	0.05	0.27	0.92	0.19	0.87	0.23	0.59	2.17	0.03	0.76	0.13	0.72	0.01	8.40
1925	1.15	0.14	0.17	0.05	0.28	1.00	0.28	0.90	0.25	0.64	2.22	0.03	0.87	0.17	0.74	0.01	8.91
1930	1.13	0.14	0.18	0.06	0.29	1.07	0.38	0.94	0.28	0.69	2.27	0.03	0.98	0.21	0.75	0.01	9.42
1935	1.17	0.15	0.20	0.06	0.30	1.14	0.30	0.92	0.30	0.76	2.31	0.04	1.00	0.24	0.83	0.01	9.74
1940	1.21	0.16	0.21	0.06	0.31	1.21	0.23	0.91	0.33	0.84	2.35	0.04	1.02	0.27	0.91	0.01	10.06
1945	1.29	0.17	0.24	0.08	0.33	1.26	0.34	0.98	0.36	0.99	2.43	0.04	1.55	0.30	1.01	0.01	11.38
1950	1.38	0.19	0.26	0.09	0.35	1.32	0.45	1.05	0.39	1.14	2.50	0.05	2.07	0.34	1.11	0.01	12.69
1955	1.46	0.20	0.36	0.10	0.39	1.41	0.50	1.22	0.43	1.40	2.61	0.05	1.99	0.40	1.55	0.01	14.08
1960	1.53	0.21	0.46	0.12	0.43	1.51	0.55	1.39	0.48	1.65	2.72	0.06	1.90	0.46	1.98	0.01	15.48
1965	1.68	0.23	0.52	0.14	0.47	1.63	0.60	1.57	0.54	2.06	2.97	0.07	2.23	0.51	2.21	0.01	17.43
1970	1.83	0.24	0.57	0.16	0.52	1.76	0.64	1.74	0.61	2.46	3.22	0.08	2.56	0.55	2.43	0.02	19.39
1975	1.93	0.27	0.65	0.17	0.54	1.87	0.73	1.97	0.72	3.34	3.66	0.09	2.89	0.63	2.77	0.02	22.22
1980	2.03	0.30	0.73	0.19	0.56	1.97	0.81	2.19	0.83	4.21	4.09	0.10	3.23	0.70	3.11	0.02	25.06
1985	2.00	0.30	0.77	0.20	0.58	1.98	0.79	2.28	1.02	5.06	4.70	0.13	3.59	0.79	3.30	0.02	27.51
1990	1.96	0.31	0.82	0.20	0.60	2.00	0.78	2.37	1.20	5.91	5.31	0.15	3.96	0.87	3.50	0.02	29.96
1995	1.92	0.32	0.87	0.21	0.62	2.01	0.76	2.47	1.39	6.76	5.91	0.17	4.33	0.96	3.69	0.02	32.41

4. COMPARISON BETWEEN EPPA4 BASE YEAR AND HISTORICAL ANTHROPOGENIC EMISSIONS

Table 18 provides the data for 1995 historical anthropogenic emissions represented in this report (where we mostly rely on the EDGAR dataset with some additional adjustments) and 1997 base year data in EPPA4 model (where we mostly rely on the US EPA estimates) as documented in Sarofim *et al.* (2006).

Table 18. Comparison of EPPA4 Base Year (1997) Emissions and Historical Database Emissions in 1995

	USA	CAN	MEX	JPN	ANZ	EUR	EET	FSU	ASI	CHN	IND	IDZ	AFR	MES	LAM	ROW	GLOBAL
Fossil CO_2 Tg																	
EPPA4	1481.41	135.60	86.34	323.43	91.71	926.04	198.63	561.45	303.37	847.80	236.30	63.89	220.03	218.23	217.84	124.59	6036.64
HISTORIC	1421.22	123.58	91.51	240.85	64.23	864.87	231.82	626.76	301.95	954.07	241.56	60.39	201.60	322.95	235.32	96.34	6079.02
CH_4 Tg																	
EPPA4	30.99	4.10	5.10	1.56	6.86	18.50	6.70	37.9	24.23	58.90	25.03	11.78	23.41	10.26	34.33	37.47	337.03
HISTORIC	45.03	4.31	6.37	2.66	6.16	21.97	9.70	53.64	17.18	48.13	10.12	2.12	27.53	10.68	27.16	40.69	333.45
N_2O Tg																	
EPPA4	1.36	0.21	0.17	0.10	0.10	1.15	0.19	0.41	0.23	1.78	0.98	0.08	1.06	0.25	0.96	0.68	9.70
HISTORIC	1.11	0.22	0.23	0.17	0.22	1.13	0.42	0.92	0.34	1.64	1.26	0.10	0.80	0.33	0.77	0.07	9.70
PFC Gg																	
EPPA4	3.00	0.93	0.44	2.60	0.32	2.18	0.24	1.91	0.80	1.60	0.60	0.02	0.24	0.20	1.00	0.30	16.39
HISTORIC	3.50	1.27	0.00	2.49	0.27	2.33	0.47	3.61	0.00	1.30	0.38	0.11	0.24	0.18	0.60	0.48	17.22
HFC Gg																	
EPPA4	39.80	0.92	0.53	15.30	0.92	22.04	0.80	3.21	1.94	0.93	0.43	0.28	0.95	0.66	2.47	0.94	92.19
HISTORIC	44.83	1.27	0.00	13.57	1.32	27.58	0.99	3.96	1.71	0.97	0.43	0.32	0.43	0.10	2.47	0.97	100.91
SF6 Gg																	
EPPA4	1.50	0.20	0.05	2.20	0.03	0.50	0.00	0.20	0.23	0.29	0.15	0.02	0.20	0.09	0.39	0.19	6.22
HISTORIC	2.18	0.26	0.03	0.77	0.04	1.01	0.01	0.35	0.10	0.61	0.22	0.02	0.10	0.25	0.06	0.01	6.00
SO_2 Tg																	
EPPA4	16.83	2.68	2.29	0.85	1.50	10.68	6.56	14.26	8.38	30.60	6.63	1.28	8.48	3.71	8.46	3.55	126.58
HISTORIC	19.78	1.73	1.09	1.15	0.94	21.13	10.14	22.15	3.82	27.11	4.09	0.55	6.18	4.02	6.67	0.05	130.60
NO_X Tg																	
EPPA4	35.91	5.04	2.15	4.44	2.89	20.30	2.66	10.20	7.11	15.28	5.73	1.97	12.78	5.45	9.54	3.58	145.03
HISTORIC	28.18	2.34	2.70	3.24	3.47	15.45	2.65	13.56	4.77	14.44	8.66	0.59	20.69	4.54	11.51	0.11	136.88
CO Tg																	
EPPA4	152.07	58.62	20.11	20.91	20.48	68.11	12.11	56.64	70.68	99.66	74.04	35.21	196.22	40.98	137.10	62.32	1125.28
HISTORIC	103.52	11.52	30.31	13.55	21.93	75.25	16.36	70.64	57.97	135.91	130.72	7.16	256.49	38.61	129.22	0.68	1099.84
VOC Tg																	
EPPA4	27.61	10.42	4.40	10.07	3.42	21.89	2.62	17.54	18.10	13.27	15.42	6.46	21.98	15.44	17.16	12.54	218.34
HISTORIC	25.09	3.51	4.12	8.30	3.05	22.99	3.76	20.62	11.50	21.60	20.07	1.42	30.99	13.05	17.57	0.09	207.73
BC Tg																	
EPPA4	0.77	0.10	0.26	0.10	0.06	0.75	0.34	0.68	0.74	2.49	1.53	0.30	2.82	0.41	1.41	0.58	13.33
HISTORIC	0.63	0.33	0.66	0.32	0.30	0.51	0.46	0.83	0.55	4.93	1.48	0.47	0.44	0.67	0.40	0.44	13.43
OC Tg																	
EPPA4	2.37	0.32	0.96	0.15	0.20	2.20	0.87	2.30	2.26	6.79	6.70	1.32	15.98	1.18	6.66	2.64	52.90
HISTORIC	2.13	1.12	2.73	0.42	0.58	1.23	1.10	2.01	1.82	11.58	4.82	2.59	6.09	2.75	1.28	1.80	44.05
NH_3 Tg																	
EPPA4	2.13	0.34	0.52	0.18	0.63	2.20	0.52	1.70	0.67	7.90	5.20	0.63	2.99	0.93	3.64	2.20	32.39
HISTORIC	1.92	0.32	0.87	0.21	0.62	2.01	0.76	2.47	1.39	6.76	5.91	0.17	4.33	0.96	3.69	0.02	32.41

5. SUMMARY AND CAVEATS

These data rely on published sources where available, but to provide a "complete" inventory of emissions from the 1890-1995 period we needed to extrapolate or interpolate for some of these substances. In many cases, data in the published sources we cite were developed using similar estimation methods. As a result, they are essentially crude approximations. Our reason for assembling these data are to use them to force an earth system model that is land-ocean as well as urban-non-urban chemistry resolving, but is otherwise 2-dimensional (resolved by latitude but not longitude). We intend to use an existing algorithm to further assign emissions to urban-non-urban areas and latitude band. Thus, it was necessary to assign emissions to the existing countries/regions in the EPPA4 model. It was also deemed preferable to have a crude estimate for unknown emissions (*e.g.,* NOx, BC, and OC from land use sources) as opposed to no estimate at all. This further assignment of emissions to regions, and assumptions used to come up with crude estimates for missing sources, leads to additional uncertainties, especially regional estimates. We believe the approach we used captures, in a rudimentary way, the differences between northern and southern hemisphere and between tropics, as well as temperate and polar regions – all useful for driving the MIT IGSM. Readers are cautioned against attributing greater accuracy to these estimates. We intend to use them only as an initial estimate in order to drive the IGSM. As such, differences between simulated and unobserved concentrations will lead us to examine, in greater detail, our modeling of removal and natural sources, as well the accuracy of these emissions inventories themselves.

6. REFERENCES

Archard, F.H., D. Eva, H.-J. Stibig, P. Mayaux, J. Gallego, T. Richards and J.-P. Malingreau (2002). Determination of deforestation rates of the world's humid tropical forests. *Science*, **297**, 999-1002.

ASL and Associates (1997). *Sulfur emissions by country and year*. Report No: DE96014790. US Department of Energy, Washington, DC.

Bond, T.C., D.G. Street, K.F. Yarber, S.M. Nelson, J.H. Woo and Z. Klimont (2004). A technology-based global inventory of black and organic carbon emissions from Combustion. *J. Geophysical Research,* **109***,* D14203, doi: 10/1029/2003JD003697.

Center for International Earth Science Information Network (CIESIN), Columbia University; International Food Policy Research Institute (IFPRI); and World Resources Institute (WRI). (2000). Gridded Population of the World (GPW), Version 2. Palisades, NY: CIESIN, Columbia University (http://sedac.ciesin.columbia.edu/plue/gpw).

Chen, Y.-H. (2003). *Estimation of Methane and Carbon Dioxide Surface Fluxes using a 3-D Global Atmospheric Chemical Transport Model*. MIT Center for Global Change Science Report 73, Cambridge, MA (http://web.mit.edu/cgcs/www/MIT_CGCS_Rpt73.pdf).

DeFries, R.S., R.A. Houghton, M.C. Hansen, C.B. Field, D. Skole, and J. Townsend (2002). Carbon emissions from tropical deforestation and regrowth based on satellite observations for the 1980s and 1990s. *Proceedings of the National Academy of Sciences*, **99**, 14,256-14,261.

Dimaranan, B.V., and R.A. McDougall (2002). *Global Trade, Assistance, and Production: The GTAP 5 Data Base*. Center for Global Trade Analysis, Purdue University (https://www.gtap.agecon.purdue.edu/).

Felzer B., D. Kicklighter, J. Melillo, C. Wang, Q. Zhuang, and R. Prinn (2004). Ozone Effects on Net Primary Production and Carbon Sequestration in the Conterminous United States using a Biogeochemistry Model. *Tellus* **56B**, 230-248.

Hertel, T. (1997). *Global Trade Analysis: Modeling and Applications*. Cambridge University Press, Cambridge, UK.

Houghton, J.T., Ding, Y., Griggs, D.J., Noguer, M., van der Linden, P.J., Dai, X., Maskell, J., and Johnson, C.A. (eds.) (2001). *Climate Change 2001: The Scientific Basis*, Cambridge University Press, Cambridge, UK.

Houghton, R.A., and J.L. Hackler (2002). Carbon Flux to the Atmosphere from Land-Use Changes. In: *Trends: A Compendium of Data on Global Change*. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A. (http://cdiac.esd.ornl.gov/trends/emis/em_cont.htm).

Houghton, R. (2003). Why are estimates of the terrestrial carbon balance so different? *Global Change Biology*, **9**, 500-509.

Lefohn, A.S., Husar, J.D., Husar, R.B. (1999). Estimating historical anthropogenic global sulfur emission patterns for the period 1850–1990. *Atmospheric Environment* **33**, 3435–3444.

Lelieveld J., P.J. Crutzen, F.J. Dentener (1998). Changing concentration, lifetime and climate forcing of atmospheric methane. *Tellus Series B-Chemical And Physical Meteorology*, **50**(2), 128-50.

Marland, G., T.A. Boden, and R. J. Andres (2005). *Global, Regional, and National Fossil Fuel CO_2 Emissions. In Trends: A Compendium of Data on Global Change*. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, TN (http://cdiac.esd.ornl.gov/trends/landuse/houghton/houghton.html).

Mayer M., R. R. Hyman, J. Harnisch, and J. Reilly (2000). *Emissions Inventories and Time Trends for Greenhouse Gases and other Pollutants.* Technical Note 1, MIT Joint Program on the Science and Policy of Global Change, Cambridge MA (http://web.mit.edu/globalchange/www/MITJPSPGC_TechNote1.pdf).

McCulloch A., P. Ashford and P.M. Midgley (2001). Historic Emissions of Fluorotrichloromethane (CFC-11) Based on a Market Survey. *Atmospheric Environment*, **35**(26), 4387-4397 (as updated at http://www.geiacenter.org/reviews/cfc11.html).

McCulloch, A., P.M. Midgley and P. Ashford (2003). Releases of refrigerant gases (CFC-12, HCFC-22 and HFC-134a) to the atmosphere. *Atmospheric Environment*, **37**, 889-902 (as updated on http://www.geiacenter.org/reviews/cfc12.html).

Morton, B.R (1964). *Numerical approximation*. London: Routledge and Kegan Paul, p.38.

Novakov, T., V. Ramanathan, J.E. Hansen, T.W. Kirchstetter, M. Sato, J.E. Sinton, and J.A. Sathaye (2003). Large historical changes of fossil-fuel black carbon aerosols. *Geophysical Research Letters*, **30**(6), 1324.

Novakov, T., S. Menon, T.W. Kirchstetter, D. Koch, and J.E. Hansen (2005). *Aerosol organic carbon to black carbon ratios: Analysis of published data and implications for climate forcing* (July 11). Lawrence Berkeley National Laboratory, Paper LBNL-57771. (http://repositories.cdlib.org/lbnl/LBNL-57771).

Olivier, J.G.J. and J. Bakker (2000). *Historical global emission trends of the Kyoto gases HFCs, PFCs and SF6*. Paper presented at the conference "SF_6 and the Environment: Emission Reduction Strategies," San Diego, CA, 2-3 November 2000. (http://www.p2pays.org/ref/22/21586.pdf).

Olivier, J.G.J. and J.J.M. Berdowski (2001a). Global emissions sources and sinks. In: *The Climate System*, Berdowski, J., R. Guicherit and B.J. Heij (eds.), A.A. Balkema Publishers/ Swets & Zeitlinger Publishers, Lisse, The Netherlands. ISBN 9058092550, pp. 33-78.

Olivier, J.G.J., J.J.M. Berdowski, J.A.H.W. Peters, J. Bakker, A.J.H. Visschedijk en J.-P.J. Bloos (2001b). *Applications of EDGAR. Including a description of EDGAR 3.0: reference database with trend data for 1970-1995*. RIVM, Bilthoven. RIVM report no. 773301 001/ NOP report no. 410200 051.

Paltsev, S., J.M. Reilly, H.D. Jacoby, R.S. Eckaus, J. McFarland, M. Sarofim, M. Asadoorian and M. Babiker (2005). *The MIT Emissions Prediction and Policy Analysis (EPPA) Model: Version 4*, MIT Joint Program on the Science and Policy of Global Change, Report 125, Cambridge MA (http://web.mit.edu/globalchange/www/MITJPSPGC_Rpt125.pdf).

Press, W.H., S.A. Teukolsky, W.T. Vetterling, B.P. Flannery (1992). *Numerical recipes in C: The art of scientific computing*. Cambridge: Cambridge University Press, pp.108-110.

Prinn, R, J. Reilly, M. Sarofim, C. Wang and B. Felzer (2005). *Effects of Air Pollution Control on Climate*, MIT Joint Program on the Science and Policy of Global Change, Report 118, Cambridge MA (http://web.mit.edu/globalchange/www/MITJPSPGC_Rpt118.pdf).

Ramaswamy, V., O. Boucher, J. Haigh, D. Hauglustaine, J. Haywood, G. Myhre, T. Nakajima, G.Y.Shi, and S. Solomon (2001). Radiative Forcing of Climate Change. In: *Climate Change 2001: The Scientific Basis*. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Houghton, J.T., Y.Ding, D.J.Griggs, M.Noguer, P.J. vna der Linden, X. Dai, K. Maskell, and C.A.Johnson (eds.), Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 881.

Sabine, C.L., M. Heiman, P. Artaxo, D.C. Bakker, C.-T. Chen, C.B. Field, N. Gruber, C. LeQue′re′, R.G. Prinn, J.E. Richey, P. Romero-Lankao, J. Sathaye, and R. Valentini (2004). Current status and past trends of the carbon cycle. In: *The Global Carbon Cycle, SCOPE Project 62*, C.B. Field and M.R. Raupach (eds.), Island Press, Washington DC, p. 17-44.

Sarofim, M., M. Asadoorian, M., J. Tay, A. Valpergue de Masin, K. See, R. Sandoval, S. Paltsev, and J. Reilly (2006). *Emissions Inventories and Time Trends for Greenhouse Gases and other Pollutants*. MIT Joint Program on the Science and Policy of Global Change, Technical Note, forthcoming.

Smith SJ, R Andres, E Conception , and J Lurz (2004). Historical Sulfur Dioxide Emissions 1850-2000: Methods and Results. Pacific Northwest National Laboratory (PNNL-14537), Pacific Northwest National Laboratory, Richland, WA (http://www.pnl.gov/main/publications/external/technical_reports/PNNL-14537.pdf).

Sokolov, A.P., C.A. Schlosser, S. Dutkiewicz, S. Paltsev, D.W. Kicklighter, H.D. Jacoby, R.G. Prinn, C.E. Forest, J. Reilly, C. Wang, B. Felzer, M.C. Sarofim, J. Scott, P.H. Stone, J.M. Melillo and J. Cohen (2005). *The MIT Integrated Global System Model (IGSM) Version 2: Model Description and Baseline Evaluation*, Report 124, MIT Joint Program on the Science and Policy of Global Change, Cambridge, MA (http://web.mit.edu/globalchange/www/MITJPSPGC_Rpt124.pdf).

Spiro, P.A., D.J. Jacob, J.A. Logan (1992). Global Inventory of Sulfur Emissions With 1º x 1º Resolution. *J. Geophysical Research-Atmospheres*, **97**(D5), 6023-6036.

Stern, D.I. (2005). Global sulfur emissions from 1850-2000. *Chemosphere*, **58**, 163-175.

Stern, D.I., and R.K. Kaufmann (1998). *Annual Estimates of Global Anthropogenic Methane Emissions: 1860-1994. Trends Online: A Compendium of Data on Global Change*. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A. (http://cdiac.ornl.gov/trends/meth/ch4.htm).

U.S. Environmental Protection Agency (US EPA) (2002). *Methane. International Analysis*. EPA Compilation (http://www.epa.gov/methane/intlanalyses.html).

U.S. Environmental Protection Agency (US EPA) (2005). *Global Anthropogenic Non-CO_2 Greenhouse Gas Emissions: 1990-2020*. Office of Atmospheric Programs, Climate Change Division (http://www.epa.gov/methane/pdfs/global_emissions.pdf).

Van Aardenne, J.A., Dentener, F.J., Olivier, J.G.J., Klein Goldewijk, C.G.M. and J. Lelieveld (2001). A 1 x 1 degree resolution dataset of historical anthropogenic trace gas emissions for the period 1890-1990. *Global Biogeochemical Cycles*, **15**(4), 909-928.