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COMPILATION AND ANALYSES OF EMISSIONS INVENTORIES FOR NOAA'S ATMOSPHERIC CHEMISTRY PROJECT

PROGRESS REPORT, AUGUST 1997

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ABSTRACT

Global inventories of anthropogenic emissions of oxides of nitrogen (NO_x) for circa 1985 and 1990 and Non-Methane Volatile Organic Compounds (NMVOCs) for circa 1990 have been compiled by this project. Work on the inventories has been carried out under the umbrella of the Global Emissions Inventory Activity (GEIA) of the International Global Atmospheric Chemistry (IGAC) Program. The 1985 NO_x inventory was compiled using default data sets of global emissions that were refined via the use of more detailed regional data sets; this inventory is being distributed to the scientific community at large as the GEIA Version 1A inventory. Global emissions of NO_x for 1985 are estimated to be 21 Tg N y^{-1}, with approximately 84% originating in the Northern Hemisphere. The 1990 inventories of NO_x and NMVOCs were compiled using unified methodologies and data sets in collaboration with the Netherlands National Institute of Public Health and Environmental Protection (Rijksinstituut Voor Volksgezondheid en Milieuhygiene, RIVM) and the Division of Technology for Society of the Netherlands Organization for Applied Scientific Research, (IMW-TNO); these emissions will be used as the default estimates to be updated with more accurate regional data. The NMVOC inventory was gridded and speciated into 23 chemical categories. The resulting global emissions for 1990 are 31 Tg N yr^{-1} for NO_x and 173 Gg NMVOC yr^{-1}. Emissions of NO_x are highest in the populated and industrialized areas of eastern North America and across Europe, and in biomass burning areas of South America, Africa, and Asia. Emissions of NMVOCs are highest in biomass burning areas of South America, Africa, and Asia. The 1990 NO_x emissions were gridded to 1° resolution using surrogate data, and were given seasonal, two-vertical-level resolution and speciated into NO and NO_2 based on proportions derived from the 1985 GEIA Version 1B inventory. Global NMVOC emissions were given additional species resolution by allocating the 23 chemical categories to individual chemical species based on factors derived from the speciated emissions of NMVOCs in the U.S. from the U.S. EPA's 1990 Interim Inventory.

Ongoing research activities for this project continue to address emissions of both NO_x and NMVOCs. Future tasks include: a) evaluation of more detailed regional emissions estimates and update of the default 1990 inventories with the appropriate estimates, b) derivation of quantitative uncertainty estimates for the emission values, and c) development of emissions estimates for 1995.

INTRODUCTION

The growing international concern about the rapid atmospheric chemistry changes over the globe and their impact on humankind led to the creation of the International Global Atmospheric Chemistry (IGAC) Project. The overall goal of IGAC is "to develop a fundamental understanding of the natural and anthropogenic processes that determine the chemical composition of the atmosphere and the interactions between atmospheric composition and biospheric and climatic processes". The IGAC research program is divided into five major research areas, called "Regional Foci". Recognizing that the oceans are both major source and

major sink regions, Focus 1 activities study the natural variability and anthropogenic perturbations of the marine atmosphere.

As part of the NOAA research activities addressing IGAC Focus 1, current emphases of the Atmospheric Chemistry Program are:

1) the North Atlantic Regional Experiment (NARE), with emphasis on intensive field studies and modeling;

2) the East Asian/North Pacific Regional Experiment (APARE), with emphasis on coordination of ground-based chemical measurements and diagnostic analyses and modeling of regional chemical processes;

3) stratospheric/upper tropospheric ozone research, with an emphasis on the development or deployment of instruments capable of measuring key chemical compounds from high-altitude jet aircraft; and

4) field observations and related analysis elucidating the role of anthropogenic aerosols in climate forcing, with an emphasis on the chemical processes involved.

A **crucial** input to these different studies within the NOAA Atmospheric Chemistry Program is quantitative estimates on the location, magnitude and time distribution of global O_3 precursors emissions. Therefore, the overall goal of this project is

to compile and analyze accurate estimates of anthropogenic emissions of ozone precursors, compiled using unified methodologies and with sufficient spatial, temporal and species resolution to serve as standard inventories for diverse needs of the NOAA Atmospheric Chemistry project.

The principal precursor emissions in the formation of ozone in the troposphere are oxides of nitrogen (NO_x) and volatile organic compounds (VOCs). Thus, work for this project is divided into two parallel tasks: 1) compilation and analysis of global inventories of NO_x, and 2) compilation and analysis of global inventories of VOCs. Here we report on the accomplishments and ongoing tasks of this project as of August 1997.

GLOBAL EMISSIONS INVENTORY ACTIVITY

The work for this project is being conducted under the umbrella of the Global Emissions Inventories Activity (GEIA) [*Molina*, 1992], a core activity (Activity 6.5 of Focus 6) of the International Global Atmospheric Chemistry (IGAC) Programme [*Galbally*, 1989]. The ultimate and very ambitious target of GEIA is to establish emissions inventories for a number of trace species, incorporating fluxes from both anthropogenic and natural sources, with recognized accuracy and enough spatial, temporal and species resolution to serve as standard inventories for

the international community of atmospheric scientists [*Benkovitz and Graedel*, 1992]. To accomplish this, GEIA has the following goals:

- To establish a framework for the development and evaluation of global emissions inventories.
- To conduct a critical survey of existing emissions inventories of compounds of major importance in global atmospheric chemistry.
- To publish inventories in the open literature and provide appropriate data files for use by scientists worldwide.

As with all other IGAC activities, GEIA tries to include all interested parties on a volunteer basis. Emissions inventory experts from individual countries, supported by local organizations, conduct their own research while maintaining contact through a network which includes FAX communication, electronic mail, and participation in periodic face-to-face meetings. The GEIA forum allows participants to discuss their work, draw on the combined expertise of their fellow members, and, most important, to coordinate their efforts so that results of their work are compatible and can be combined with a minimum of effort.

Co-chairs of the GEIA Working Group on Anthropogenic Emissions of SO_2 and NO_x are the principal investigator, Dr. Carmen Benkovitz, and Dr. M. Trevor Scholtz, director of the Canadian Center for Global Emissions Inventories, a project of Atmospheric Environment Service, Canada. Dr. Benkovitz is also a participant in the GEIA Working Group on Anthropogenic Emissions of Volatile Organic Compounds (VOCs), which is chaired by Dr. J.J.M. Berdowski of the Division of Technology for Society of the Netherlands Organization for Applied Scientific Research, (IMW-TNO).

COMPILATION OF INVENTORIES OF ANTHROPOGENIC EMISSIONS OF NO_x

NO_x Emissions for Base Year 1985

The compilation of NO_x inventories of anthropogenic emissions for base year 1985 was a project within the GEIA Study Group on Anthropogenic Emissions of SO_2 and NO_x and included scientists from The Norwegian Institute for Air Research, Kjeller, Norway, The Norwegian Meteorological Institute, Oslo, Norway, and Lawrence Livermore National Laboratory, Livermore, CA, USA [*Benkovitz*, 1994; *Benkovitz*, 1995; *Benkovitz*, 1996]. The work is detailed in Benkovitz et al. [1996]; the following is a brief summary and a reprint of the journal article is included in the Appendix. To develop the global inventory of anthropogenic emissions of NO_x for 1985 emissions estimates compiled by Dignon [1992] were used as the "default" emissions for base year 1985. The default values are used for geographic areas where there were no other emissions estimates available. The default inventory allocated industrial emissions to a 1°×1° grid based on a 1984 gridded population file (J. Logan, Harvard University, manuscript in

preparation, 1997). Emissions from more detailed regional inventories for the United States and Canada to 60°N [*Saeger et al.*, 1989], Europe [*Bouscaren*, 1992; *Eliassen and Saltbones*, 1983], Middle East and North Africa [*Sandnes and Styve*, 1992], Asia [*Akimoto and Narita*, 1994; *Kato and Akimoto*, 1992], the Asian part of the former USSR (J. Pacyna, personal communication, 1995), South Africa (S.M. Lloyd, South African Department of National Health and Population Development, personal communication, 1993), and Australia [*Farrington*, 1988; *Horseman and Carnovale*, 1989] were evaluated by comparison with estimates in the literature and other known surrogate data such as information on power plants, smelters and other large sources before replacing the regional emissions in the default inventory. The global anthropogenic emissions of NO_x for 1985 total 21 Tg N y^{-1}; approximately 84% of these emissions originate in the Northern Hemisphere, with the midlatitude regions of both hemispheres contributing approximately 88% of the total emissions. This inventory is known as the GEIA Version 1A inventory of anthropogenic emissions of NO_x and is now available to the scientific community at large through the GEIA Data Management project; it has become the "*gold standard*" in Atmospheric Chemistry research.

NO_x Emissions for Base Year 1990

A global inventory of anthropogenic NO_x emissions by country for 1990 has been developed in collaboration with the Netherlands National Institute of Public Health and Environmental Protection (Rijksinstituut Voor Volksgezondheid en Milieuhygiene, RIVM) and the Division of Technology for Society of the Netherlands Organization for Applied Scientific Research, (IMW-TNO). The Dutch effort is part of the Emission Database for Global Atmospheric Research (EDGAR) project [*Baars et al.*, 1991; *Berdowski*, 1992; *Olivier et al.*, 1994]. This section describes the methodologies and data sources used to compile the initial version of the by country inventory and at BNL the gridded, speciated, and 2-level vertical resolution version of this inventory. Additional work is in progress to refine these estimates.

Methodology and Data Sources

The general formulation used to estimating by country emissions from each source is:

$$emissions = (activity\ rate) \times (emission\ factor)$$

where *activity rate* is the amount of fuel burned, or units produced, etc. and *emission factor* is the emissions per unit activity rate.

NO_x sources were divided into four main source sectors and several sub-sectors according to the sectoral definitions used by the IEA [1992b]; the sector and sub-sector definitions used in this work are presented in Table 1. Activity rates for each sub-sector were obtained on a per country basis, with the IEA energy statistics 1971-1992 being the primary data source for 112 IEA countries. Calculations were extended to 71 countries using IEA totals and country splits according to UN data [1993e; 1994a; 1994b]. For the Biofuel combustion sector the activity

levels for total biomass use per country were taken from [*Hall et al.*, 1994] except for some industrialized countries.

Uniform global emission factors for NO_x were derived from a number of sources. For example, for fossil fuel combustion, the IPCC recommended data from Olivier et al., [1995]; these data were used for combustion of coal and oil products. Data from Veldt et al. [*Veldt and Berdowski*, 1995a] were used as the emission factors for the Biofuel and Industrial processes sectors. Default emission factors were taken from TNO Emission Registration (1987, 1990, and 1992), US EPA AP-42 [*U.S. Environmental Protection Agency*, 1985], and the AIRCHIEF CD-ROM system. For Biomass and Agricultural waste burning, the default emission factors were taken from Andrae [1991].

BNL's main contribution to the collaborative effort were: a) the development of a global coal production map for 1990 for the U.S., b) providing data on oil and gas production in the US, and c) providing data from the inventories compiled for the National Acid Precipitation Assessment Program (NAPAP) [*Saeger et al.*, 1989]. To develop the 1990 coal production map for the U.S., the location and status (active or inactive) for U.S. mines were assembled, mainly from the information in the National Energy Information Center (NEIC) database at the Washington office of the Bureau of Mines (D. Teeters, U.S. Bureau of Mines, Intermountain Field Operations Center, personal communication, 1996). A three-tier search - by city, mine name and zip code - was done to identify the mines and their locations. For mines which did not figure in the NEIC database, the locations were approximated by the latitude and longitude of the city or the centroid of the county where the mine is located; this information was derived from several geographic atlas. The oil and gas production information was based on the World Petrochemical Survey 1993 from the Oil and Gas Journal Energy Database (PennWell Publishing Company, Tulsa, OK). Data files for the NAPAP inventory were acquired from the U.S. Environmental Protection Agency (J.D. Mobley, personal communication, 1996).

Development of the gridded inventory

BNL gridded the by country emissions to a 1°×1° grid and then provided seasonal resolution, speciation to NO and NO_2, and two level-vertical resolution - surface and greater than 100 m. Except for sub-sectors Aircraft and International shipping in Fossil fuel combustion sector and sub-sectors Deforestation and Large biomass burning in Land use/Waste treatment sector the by-country emissions for all other sectors were allocated to a 1°×1° according to a gridded 1990 population file developed by Li [1996]. This file uses the 1990 UN country codes, including the post-cold-war political realignments, with the following additional "countries": Canary Islands, Gaza Strip, Guernsey, Israeli-occupied-territories, Jan-Mayen, Jersey, St. Helena, St. Martin. To reconcile the country definitions in the population and in the emissions files, emissions for East and West Germany were added and assigned to the UN code for Germany. The USSR emissions were split among its present republics, Azerbaijan, Armenia, Belarus, Estonia, Georgia, Kazakhstan, Kyrgystan, Lithuania, Latvia, Russia, Tadzhikistan, Turkmenistan, Ukraine, and Uzbekistan on the basis of population. Similarly, emissions from Czechoslovakia

were assigned to the Czech-Republic and Slovakia by population. Countries like Netherland Antilles, Panama, Yemen, and St. Helena had different UN code in the emissions and population files. The codes in the emissions file were incorporated in the population file. Jersey and Guernsey, which were part of the population file but not the emission file, were merged with the United Kingdom; similarly, the Gaza-strip and the Israeli-occupied-territories were merged with Israel.

For the Aircraft and International Shipping subsectors gridded data developed for EDGAR Version 2.0 (EDGAR V2) were incorporated directly into the final emissions. For sub-sectors Deforestation and Large Biomass burning, although by-country emissions were available, in the absence of a suitable surrogate gridded file, gridded data from EDGAR V2 were also used . This allowed maintenance of the spatial allocation information as well as compatibility and transparency between our gridded inventory and the original EDGAR V2 data.

The GEIA Version 1B inventory of NO_x emissions for 1985 [*Benkovitz et al.*, 1996] (M.T. Scholtz, ORTECH International, Toronto, Canada, personal communication, 1996) presents seasonal emissions for NO and NO_2 with 2-level vertical resolution. From this inventory at each grid cell the fraction of NO and NO_2 emissions for each season and at each vertical level were calculated. These fractions where then applied to the total gridded NO_x emissions for 1990 to obtain the by season, speciated, two-level inventory.

Initial results

Global emissions of NO_x for 1990 are estimated to be approx 31 Tg N. Summaries by geographic region are presented in Table 1 and Figure 2: summaries by sectors are presented in Table 1 and Figure 3. The U.S.A. contributes approximately 24% of the global emissions, Western Europe contributes approximately 13%, and CIS region (Russia and the Baltic republics) and the China region (China, Hong Kong, Kampuchea, Laos, Macau, Mongolia, North Korea, Taiwan, and Vietnam) each contribute approximately 11%. Emissions from fossil fuel combustion contribute 70% of the global total, with more than half of these emissions originating in the USA, OECD Europe, the former USSR, and China regions. The Land use/waste treatment sector contributes 20% of the global emissions, with Industrial processes and Biofuels use sectors contributing approximately 5% each. In the Latin America and Africa regions the Fossil fuel combustion sector contributes less than 50% of the regional emissions due to large emissions from the Land use/waste treatment sector.

The Road transport sub-sector contributes 44% and the Power generation sub-sector contributes 29% of the global emissions from the Fossil fuel combustion sector. The China+ region contributes about 25% of the emissions from the Industrial sub-sector and over 15% to the emissions from Residential sub-sector. For the India+ and Japan regions the Transportation sub-sector has a relatively high contribution of about 15% and 48% respectively of the regional emissions from the Fossil Fuel Combustion sector, which is probably the result of high coal consumption in rail transport.

Emissions from the Biofuel combustion and Industrial processes sectors are minor compared to the other two main source sectors. Global emissions from the Biofuel Combustion sector in 1990 are 1.55 Tg N; approximately 80% of these emissions are contributed by the residential sub-sector, where fuel wood is the dominant type. The remaining 20% are contributed by the Industrial sub-sector (excluding coke ovens, refineries, gas works, etc.). As seen from Table 1, two groups of regions can be distinguished in the Industrial and Residential sub-sectors of the Biofuel combustion sector: developed regions and less developed/developing regions. The majority of the emissions from the Biofuel combustion sector for developed countries such as the USA, Western Europe, Canada, etc. are from Industrial sub-sector; USA and Western Europe contribute 50% of the emissions from this sub-sector. For the less developed/developing countries, the Residential sub-sector contributes the large majority of emissions from the Biofuel combustion sector; India+ (20%), China+(30%), Africa (15%) and Latin America (9%) together contribute approximately 75% of the global emissions from this sub-sector.

More than 70% of the emissions from the Industrial Processes sector are contributed by the building material processes included in the Cement sub-sector. The Iron & Steel sub-sector contributes another 20%, and the Chemicals sub-sector, mainly the production of Nitric Acid and Ammonia, contributes remaining 10% to these emissions. China (14%) and Western Europe(12%) are the largest contributors to emissions from the Cement sub-sector, while the former USSR is the largest contributor to the emissions from Iron & Steel sub-sector.

The Large scale biomass burning and the Agricultural waste burning sub-sectors contribute approximately 83% of the global emissions from the Land use/Waste treatment sector. Large scale biomass burning occurs predominantly in tropical regions of Africa and Latin America, where this sub-sector contributes about 35% and 11% respectively of global emissions from this sector. These two regions contribute approximately 97% of the emissions from Large scale biomass burning sub-sector. Africa and Latin America are also the largest contributors to Deforestation sub-sector, contributing 78% of the emissions for this sub-sector. The India+ and China+ regions contribute approximately 36% of emissions from Agricultural waste burning sub-sector.

In general the distribution of global NO_x emissions is largely dependent on the local economic structure and availability of resources, whether it is the use of cement, the production of metals, or regional agricultural practices. Although in a number of regions emission reduction technologies are being applied to some extent in the use of coal for power generation, in the automobile industry, and in cement production, these sectors only contribute slightly over half (54%) of global NO_x emissions from anthropogenic sources. Geographical distribution of the global NO_x emissions for 1990 is presented in Plate 2.

Global NO_x emissions for 1990 are approximately 10 Tg N more than the global emissions for 1985 in the GEIA Version 1 inventories. The majority of this difference is due to additional information developed for the 1990 inventory, mainly in the Biofuel Combustion

sector, in the Land use/Waste treatment sector, and in the Air and International Shipping sub-sectors of the Fossil Fuel Combustion sector.

COMPILATION OF INVENTORIES OF ANTHROPOGENIC EMISSIONS OF VOCs

Methodology and Data Sources

An inventory of anthropogenic emissions of Non-Methane Volatile Organic Compounds (NMVOCs) for base year 1990 has been developed as a collaborative effort with the Netherlands National Institute of Public Health and Environmental Protection (Rijksinstituut Voor Volksgezondheid en Milieuhygiene, RIVM) and the Division of Technology for Society of the Netherlands Organization for Applied Scientific Research, (IMW-TNO). NMVOCs addressed in this inventory include all anthropogenic emissions of all organic compounds that exist in the gaseous state at ambient conditions as well as semi-volatile organic compounds from some large contributing source sectors, except for methane and fluorocarbons. This section describes the methodologies and data sources used to compile the initial version of a gridded, speciated version of this inventory. At BNL speciation to the individual chemical compounds was added to the inventory. Additional work is in progress to refine these estimates.

The general formulation used to estimate emissions has been described in the previous section. For some sources the emission rates are influenced by environmental parameters, for example, evaporation losses from traffic; these effects were taken into account when estimating their emissions. For some source sectors, such as solvent use, *"NMVOC emissions = use = sales"* is valid, but for other sectors emission factors must be used. Uniform global emission factors for NMVOCs were derived from a number of references. For example, for biomass burning, including agricultural waste burning, the emission factors from Veldt and Berdowski [*Veldt and Berdowski*, 1995b] were used. Many other references for activity data and emission factors were used, the most important being Passant [*Passant*, 1993] and trade journals such as Eurocoat, PaintIndia, Farbe & Lack, European Chemical News, Chemical & Engineering News, Rubber Statistical Bulletin.

An initial estimate of global emissions of NMVOCs from anthropogenic activities was compiled by Veldt [*Veldt*, 1993], and adapted by Berdowski [*Berdowski*, 1994]. Anthropogenic sources contributing to NMVOC emissions were classified according to the source sectors presented in Table 2 and prioritized according to their estimated contribution to these emissions. Total NMVOC emissions were estimated for these source sectors and then speciated to the chemical categories presented in Table 4.

BNL's main contributions to the collaborative effort were: a) the development estimates of the worldwide production of petrochemicals, and b) locating world wilde oil production fields. For the development of estimates of worldwide production of petrochemicals the main references were the World Petrochemical Survey for 1989, 1990, 1991, and 1993 from the Oil and Gas Journal Energy Database (PennWell Publishing Company, Tulsa, OK), the United Nations

Industrial Statistics Yearbook 1989 [*United Nations*, 1992] and various articles in trade publications [1991a; 1991b; 1991c; 1991d; 1991e; 1992a; 1992c; 1993a; 1993b; 1993c; 1993d]. The petrochemicals of interest included ammonia, methanol, aromatics, cumene, benzene, ethylbenzene, ethanol, ethylene, ethylene-dichloride, low density polyethylene, high density polyethylene, polyethylene, toluene, xylene mix, para xylene, polyvinyl chloride, vinyl chloride, acetic acid, acetone, styrene, polystyrene, propylene, and polypropelene. Approximately 2,000 oil production fields were located; a summary of the located oil fields by country is presented in Table 6. The work was performed by Diane Hirschl, a Chemical Engineering student from Washington University in St. Louis supported by the DOE Science and Engineering Research Semester (SERS) and the DOE Summer Student Program.

BNL added further species information to the NMVOCs emissions by speciating each chemical category into individual chemical species according to the following relationship:

$$E_{AC} = E_{BC} \times (Speciation\ factor)_{AB}$$

where E_{AC} are the emissions of chemical species A for source sector C and E_{BC} are the emissions of chemical category B from source sector C. Speciation factors for chemical species A in chemical category B were developed as follows. The U.S. Environmental Protection Agency (EPA) compiles detailed inventories of VOC emissions by Source Classification Code (SCC), a classification which describes the source activity. EPA has also developed VOC speciation data, which allows speciation of VOC emissions to individual chemical species [*Shareef and Bravo*, 1993]; the data are presented by SCC and include the name and weight percent of each chemical species emitted by the source sector. The total VOC emission values from the EPA 1990 Interim Inventory [*U.S. Environmental Protection Agency*, 1993] were aggregated by SCC and speciated emissions for each SCC were calculated using the appropriate speciation factors. Methane, isoprene, and terpene emissions were discarded, the last two species because these are emitted by biogenic sources. Due to the lack in detail in some EPA NMVOC profiles, 'practical' decisions had to be made in assigning certain chemical compounds present in the U.S. inventory to the global chemical categories. For example, because benzaldehyde is both an aromatic and an aldehyde, it could be assigned to either Other aromatics or to Other alkanals. Speciated emissions from each SCC were then aggregated into the source sectors presented in Table 3 The individual chemical species from this list were classified according to the chemical categories defined for the global inventory, and for each source sector, emissions were aggregated by these categories. Speciation factors for each source sector and chemical category where derived as the weight fraction of the emissions of each chemical species in each chemical category.

Initial Results

In the following discussion we include statistics from both the global NMVOC inventory developed in this project and from the U.S. EPA interim inventory for 1990 used to develop the by-species factors used in this project. The two inventories include somewhat different sources in some source sectors. For example, in the global inventory the Aircraft sector includes only

aircraft landing and take off (LTO) cycles, whereas the US inventory includes not only LTOs, but also engine testing for turbojets.

Table 2 and Figure 3 present the global NMVOC emissions by source sector; Table 3 and Figure 4 present the US emissions by the same source sectors. Total global emissions are estimated at 173 Gg NMVOC; total US emissions are estimated at 14.5 Gg NMVOC. In the global inventory, the Large biomass burning sector is the largest contributor to the global NMVOC emissions at approximately 20%, followed by small combustion sources (residential, etc.) and mobile sources, which contribute approximately 18% each. In the U.S. approximately 34% of the anthropogenic emissions of NMVOC are contributed by the Solvent use sector, followed by Miscellaneous sector at approximately 16% and Chemical bulk production and Mobile sources at approximately 12% each.

Table 4 and Figure 5 present the global NMVOC emissions by chemical category; Table 5 and Figure 6 present the US NMVOC emissions by the same chemical categories. Alkanes > C_5 are the largest contributors to the global emissions of NMVOCs at approximately 13%, followed by Acids which contribute approximately 11% and Butanes, which contribute approximately 8%. Alcohols contribute approximately 15% to the NMVOC emissions in the U.S., and alkanes > C_5 contribute approximately 14%.

Plate 3 presents the geographic distribution of the global NMVOC emissions. The high contribution of the large biomass burning sector in parts of Central Africa and Latin America is evident in this plot.

CURRENT AND FUTURE WORK

Emission inventories are never complete and never correct; therefore one of the principal tasks of the current work is to refine the emissions estimates of NO_x and NMVOCs for 1990. The GEIA Working on Anthropogenic Emissions of SO_2 and NO_x is using the 1990 NO_x inventory described here as the default emissions values. The group will search for and evaluate regional inventories for 1990; if appropriate, these data will be substituted for the default values in this inventory. The updated inventory will become the official GEIA inventory for 1990. Additional and updated statistics on activity rates and new work on emission factor are being sought, evaluated and incorporated into the appropriate inventories. Special attention will be paid to the "factors' developed at BNL to speciate the global chemical categories into individual chemical compounds. A search will be made to obtain statistical estimates of uncertainly for the emissions. Though a qualitative uncertainly estimate can be readily developed by assigning different scale levels to different regions on the basis of degree of regional detail and the data used to prepare the emission estimates, a more rigorous, quantitative uncertainly estimate will be sought.

Another task in this project is the estimation of global emissions of NO_x and NMVOCs from anthropogenic sources for the base year 1995. Activity rate data and emission factors for

this new base year are being identified and examined. The methodologies used to date will be reviewed in light of the new information, and will be modified as appropriate. Emissions will be estimated as an iterative process, the basic by-country values first. Surrogate data needed to give additional temporal, spatial and speciation details will follow the basic work.

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Source/sub-sector Region	TOTAL	CAN	USA	LAT. AM.	AFRICA	W.EUR	E.EUR	CIS	M.EAST	INDIA+	CHINA+	E.ASIA	OCEAN	JAPAN	INT. SHIP
Fossil fuel combustion	21,900	503	6,902	1,205	739	3,517	613	2,862	682	790	2,174	612	375	697	229
Industrial	3,310	47	787	109	73	354	104	594	52	169	821	64	27	110	0
Power generation	6,286	93	1,961	149	289	665	233	1,268	138	308	837	126	137	83	0
Other Transformations	708	19	153	54	21	129	27	97	47	16	57	30	9	49	0
Residential.	864	20	153	29	14	199	34	164	47	13	133	26	4	30	0
Road transport	9,593	299	3,557	825	325	2,039	205	564	368	261	258	332	182	377	0
Non-road land transport	342	12	54	12	2	35	5	105	1	17	56	10	6	26	0
Air (domestic+international)	568	14	236	26	15	95	5	70	30	8	13	23	10	23	0
International shipping	229	0	0	0	0	0	0	0	0	0	0	0	0	0	229
Biofuel Combustion	1,555	16	135	79	260	47	7	15	46	345	472	122	10	0	0
Industrial	306	15	115	18	17	44	6	14	2	40	15	16	4	0	0
Residential	1,249	1	20	61	243	3	1	1	44	305	457	106	6	0	0
Industrial processes	1,467	18	96	96	51	259	75	222	76	58	287	90	10	128	0
Iron & steel	292	1	10	13	2	59	20	68	3	5	46	14	3	48	0
Chemicals	132	6	22	6	2	17	10	28	3	3	30	2	0	3	0
Cement	1,044	11	65	77	47	183	45	125	70	50	211	75	7	77	0
Land use/waste treatment	6,166	45	185	1,370	2,677	184	45	213	166	617	348	283	21	11	0
Deforestation	1,083	0	0	508	337	0	0	0	0	78	49	111	0	0	0
Savannah burning	2,866	0	0	671	2,133	0	0	0	0	11	23	27	0	0	0
Agricultural waste burning	2,218	45	185	191	207	184	45	213	166	528	276	146	21	11	0
Total	31,088	582	7,319	2,750	3,728	4,007	740	3,312	971	1,810	3,282	1,108	416	836	229

Notes:

Fossil Fuel Other transformations sub-sector: Refineries, coke ovens, blast furnaces, etc., including fuel combustion for fuel extraction.
Industrial Processes Iron & Steel sub-sector: Sum of sinter and crude steel production.
Industrial Processes Chemicals: Sum of nitric acid and ammonia.
CIS region includes Russia and the Baltic republics (Estonia, Lithuania, and Latvia).
India+ region includes Bangladesh, Bhutan, India, Maldives, Myanmar, Nepal, Pakistan, and Sri Lanka.
China+ region includes China, Hong Kong, Kampuchea, Laos, Macau, Mongolia, North Korea, Taiwan, and Vietnam.
East Asia region includes Brunei, Indonesia, So. Korea, Malaysia, Papua New Guinea, Philippines, Singapore, Thailand and East Timor.
Oceania regions includes Australia, New Zealand and all Pacific Islands.

Table 1. Global anthropogenic NO_x emissions in 1990 (Gg N).

Source Sector	Emissions (1,000 kg)	% of total
Small scale combustion	31,163,139	17.96
Mobile sources	30,791,358	17.75
Solvent Use	21,890,370	12.62
Oil & gas production	26,013,879	14.99
Oil refining	4,434,659	2.56
Gasoline distribution	3,043,078	1.75
Chemical bulk production	1,524,259	0.88
Large combustion plants	1,545,091	0.89
Waste Incineration	9,245,337	5.33
Large biomass burning	34,172,053	19.70
Aircraft (LTO only)	45,710	0.03
Miscellaneous	9,622,273	5.55
Total	173,491,206	

Table 2. Global anthropogenic emissions of non-methane hydrocarbons for 1990.

Source Sector	Emissions (1,000 kg)	% of total
Large combustion plants	82,278	0.57
Oil & gas production	125,182	0.86
Aircraft	179,851	1.24
Oil refining	194,825	1.34
Gasoline distribution	427,881	2.95
Small scale combustion	651,827	4.50
Large biomass burning	1,016,088	7.01
Waste Incineration	1,034,515	7.14
Mobile sources	1,716,994	11.85
Chemical bulk production	1,775,508	12.26
Miscellaneous	2,338,299	16.14
Solvent Use	4,944,697	34.13
Total	14,487,945	

Table 3. Anthropogenic emissions of non-methane hydrocarbons in the U.S. for 1990.

Species	Emissions (1,000 kg)	% of total
Alcohols	10,692,400	6.16
Ethane	8,215,890	4.74
Propane	7,626,570	4.40
Butanes	14,060,300	8.10
Pentanes	12,317,500	7.10
Hexanes & higher alkanes	23,217,700	13.38
Ethene	10,267,100	5.92
Propene	4,771,410	2.75
Ethyne	4,008,710	2.31
Other alk(adi)enes & alkynes	6,790,910	3.91
Benzene	5,802,990	3.34
Toluene	6,674,390	3.85
Xylene	4,461,370	2.57
Trimethylbenzenes	833,224	0.48
Other aromatics	3,831,390	2.21
Esters	2,567,490	1.48
Ethers	4,311,750	2.49
Chlorinated HCÆs	2,401,320	1.38
Methanal	1,964,480	1.13
Other alkanals	4,760,610	2.74
Ketones	3,019,000	1.74
Acids	18,542,800	10.69
Others	12,351,900	7.12
Total	173,491,204	

Notes:

Other category includes: HCFC's, Ethane nitrile, and nonspeciated compounds.

Isoprenes and Monoterpenes are emitted mainly by biogenic sources and thus were not included in the speciation of these emissions.

Table 4. Global anthropogenic emissions of non-methane hydrocarbons for 1990.

Species	Emissions (1000 kg)	% of total
Trimethylbenzenes	31,453	0.22
Ethyne	176,804	1.22
Propene	177,076	1.22
Acids	180,771	1.25
Propane	290,025	2.00
Other aromatics	300,133	2.07
Ethane	331,405	2.29
Other alkanals	387,169	2.67
Xylene	392,247	2.71
Pentanes	392,989	2.71
Butanes	473,606	3.27
Ethers	506,036	3.49
Ketones	569,251	3.93
Ethene	700,786	4.84
Toluene	718,154	4.96
Benzene	762,020	5.26
Esters	860,824	5.94
Other alk(adi)enes & alkynes	898,661	6.20
Other	992,043	6.85
Chlorinated HCs	1,122,480	7.75
Hexanes & higher alkanes	2,056,180	14.19
Alcohols	2,167,830	14.96
Total NMVOC	14,487,943	100

Notes:

Other includes nonspeciated compounds (can be anything) and chemical streams which were listed as 'Unidentified' in the EPA speciation profiles.

Table 5. Anthropogenic emissions of non-methane hydrocarbans in the U.S. for 1990.

Country	Number Oilfields	Country	Number Oilfields
Abu Dhabi	16	Jordan	1
Algeria	46	Kuwait	8
Argentina	11	Malaysia	33
Barbados	1	Morocco	6
Benin	1	Neutral Zone	5
Bolivia	28	New Zealand	7
Brunei	8	Nigeria	175
China (Taiwan)	6	Pakistan	22
Cameroon	18	Peru	28
Congo	11	Phillipines	6
Dubai	6	Qatar	5
Ghana	1	Ras al Khaimah	1
Guatamala	7	Sharjah	2
India	27	Suriname	1
Iran	36	Trinidad	28
Iraq	20	Yemen, North	6
Ivory Coast	2	Zaire	15
Japan	14		

Table 6. Number of producing oilfields located for each country.

PLATE CAPTIONS

Plate 1. Distribution of the global anthropogenic emissions of NO_x for 1985 (Benkovitz, 1996).
Plate 2. Distribution of the global anthropogenic emissions of NO_x for 1990.
Plate 3. Distribution of the global anthropogenic emissions of NMVOCs for 1990.

FIGURE CAPTIONS

Figure 1. Contributions by geographic region to the global anthropogenic emissions of NO_x for 1990. Contributions < 1% are omitted.
Figure 2. Contributions by sector to the global anthropogenic emissions of NO_x for 1990. Contributions < 1% are omitted.
Figure 3. Contributions by sector to the global anthropogenic emissions of non-methane hydrocarbons (NMVOCs) for 1990. Contributions < 1% are omitted.
Figure 4. Contributions by sector to the U.S. anthropogenic emissions of non-methane hydrocarbons (NMVOCS) for 1990. Contributions < 1% are omitted.
Figure 5. Contributions by chemical categories to the global anthropogenic emissions of non-methane hydrocarbons (NMVOCs) for 1990. Contributions < 1% are omitted.
Figure 6. Contributions by chemical categories to the U.S. anthropogenic emissions of non-methane hydrocarbons (NMVOCS) for 1990. Contributions < 1% are omitted.

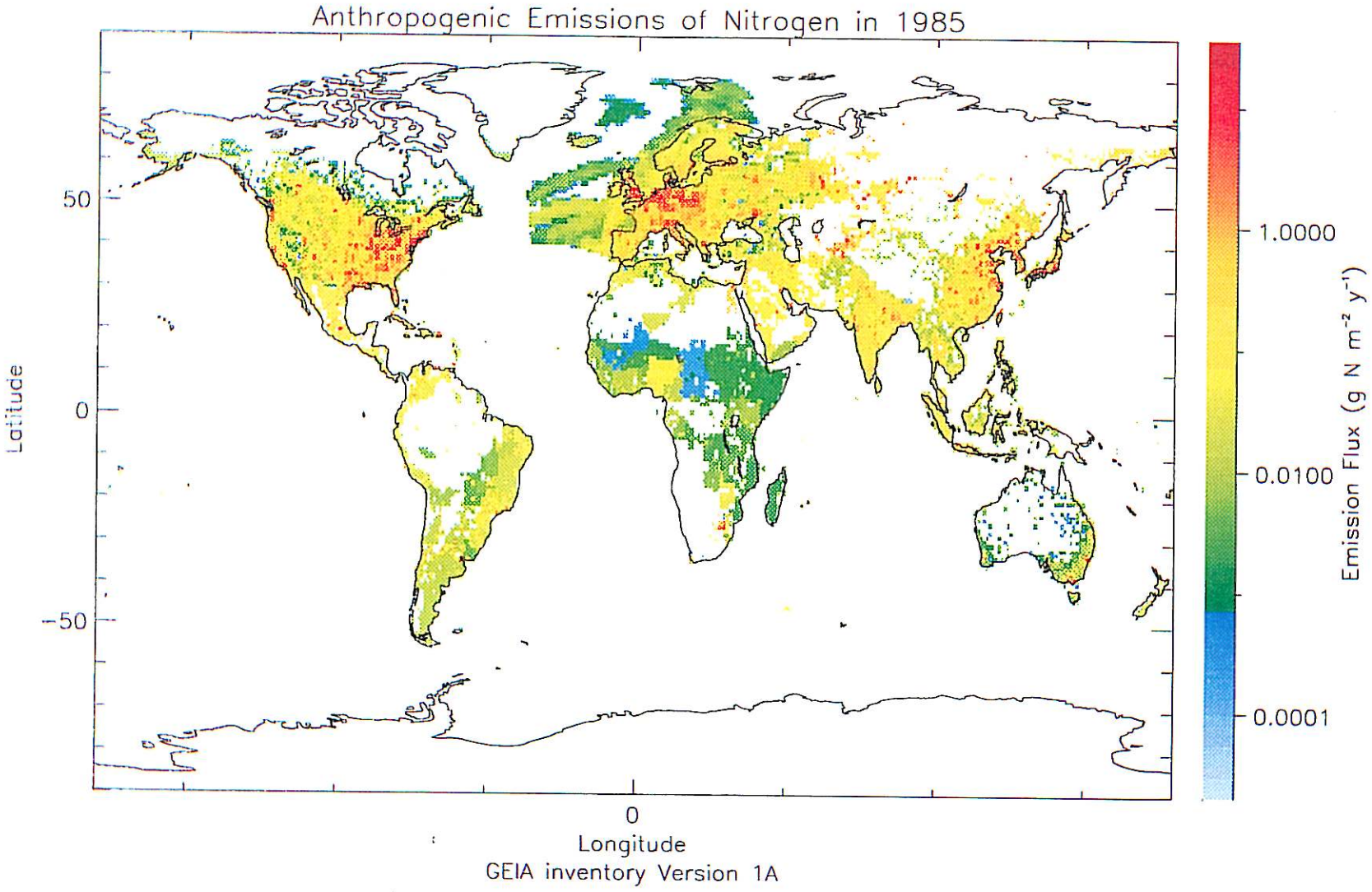
Anthropogenic Emissions of Nitrogen in 1985
50
0
-50
Latitude
0
Longitude
GEIA inventory Version 1A
1.0000
0.0100
0.0001
Emission Flux (g N m^{-2} y^{-1})

Plate 1

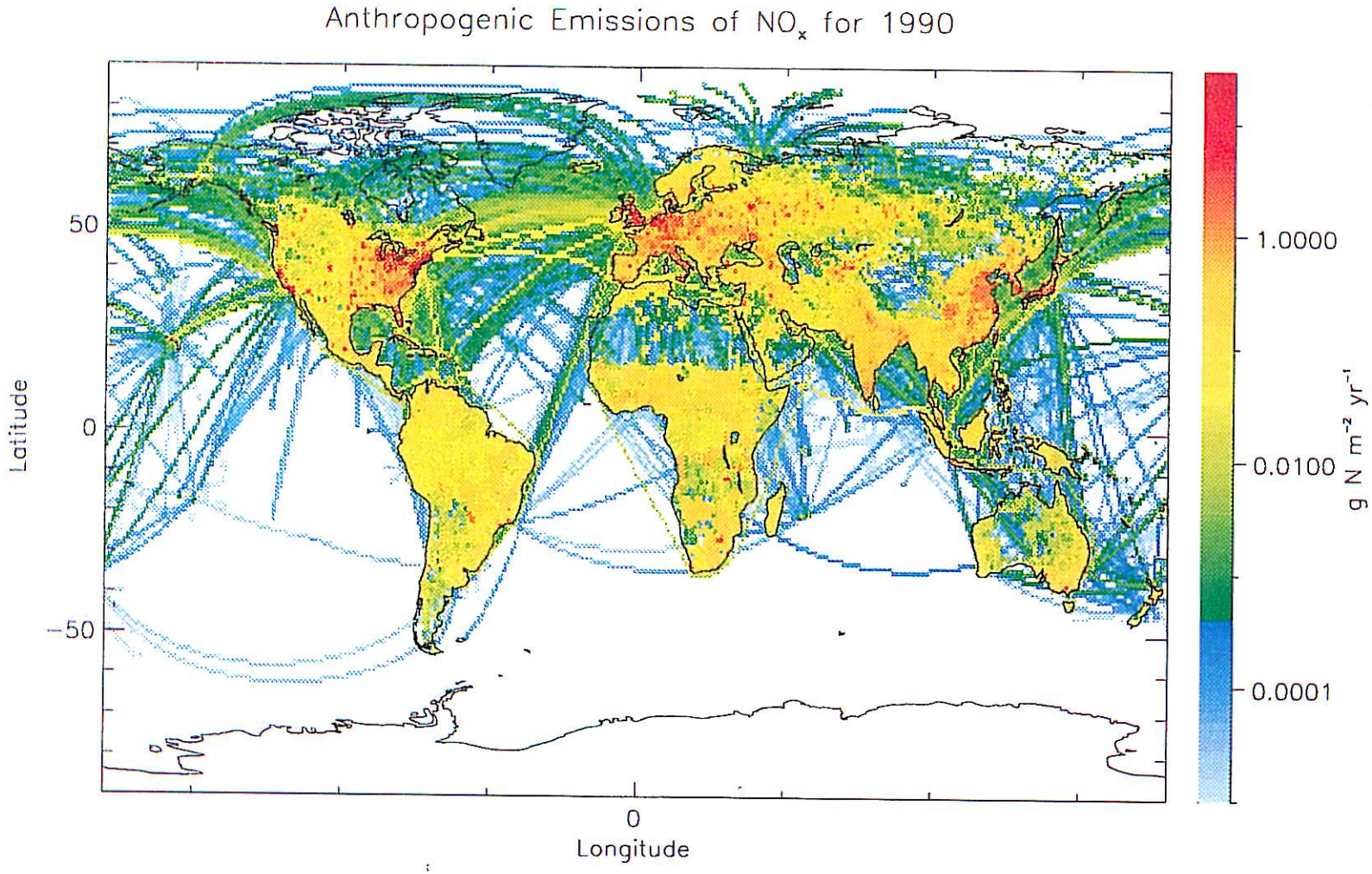
Anthropogenic Emissions of NO_x for 1990
Latitude
50
0
−50
0
Longitude
1.0000
0.0100
0.0001
g N m^{-2} yr^{-1}

Plate 2

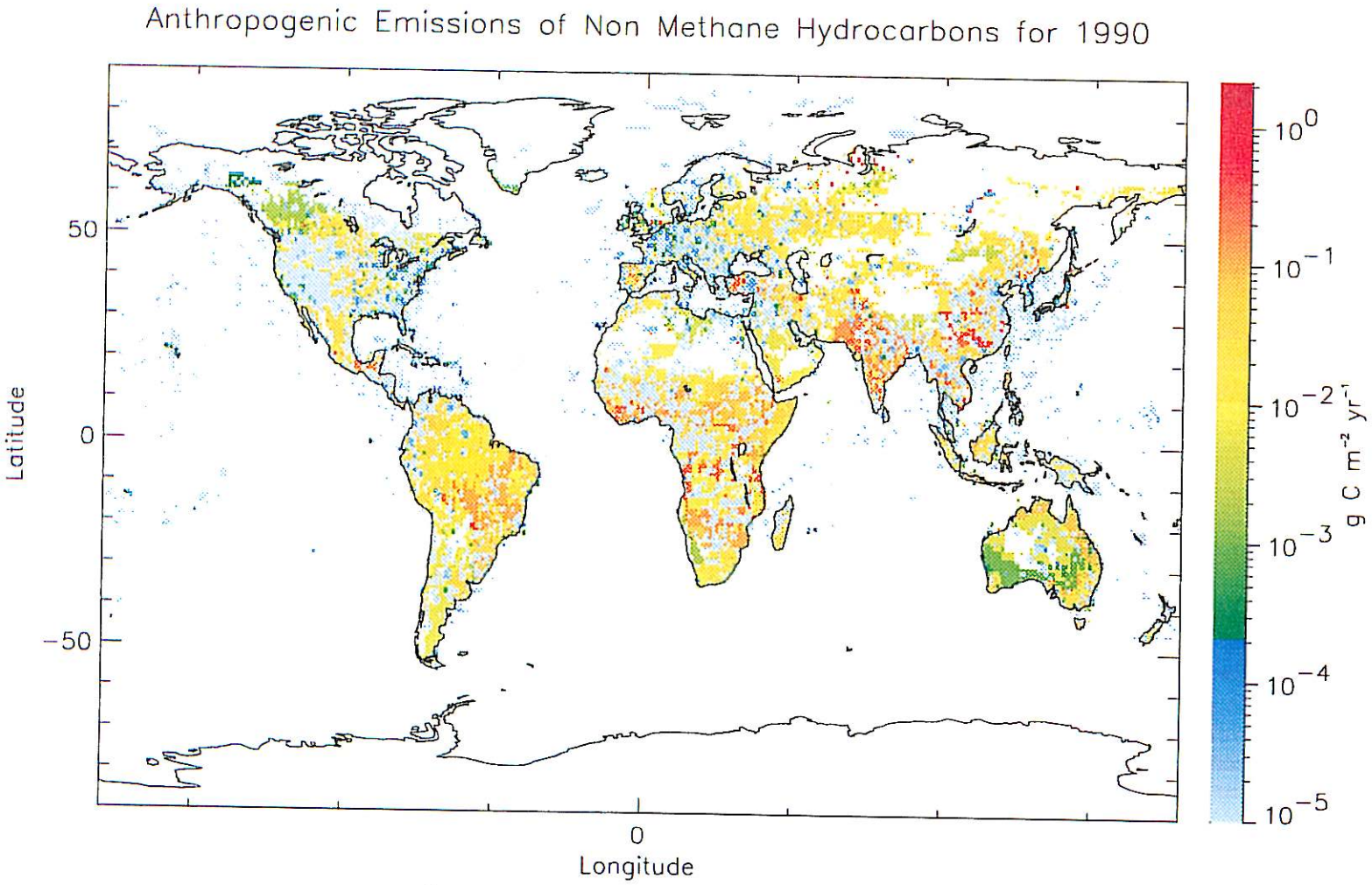
Anthropogenic Emissions of Non Methane Hydrocarbons for 1990
Latitude
50
0
−50
0
Longitude
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
g C m^{-2} yr^{-1}

Plate 3

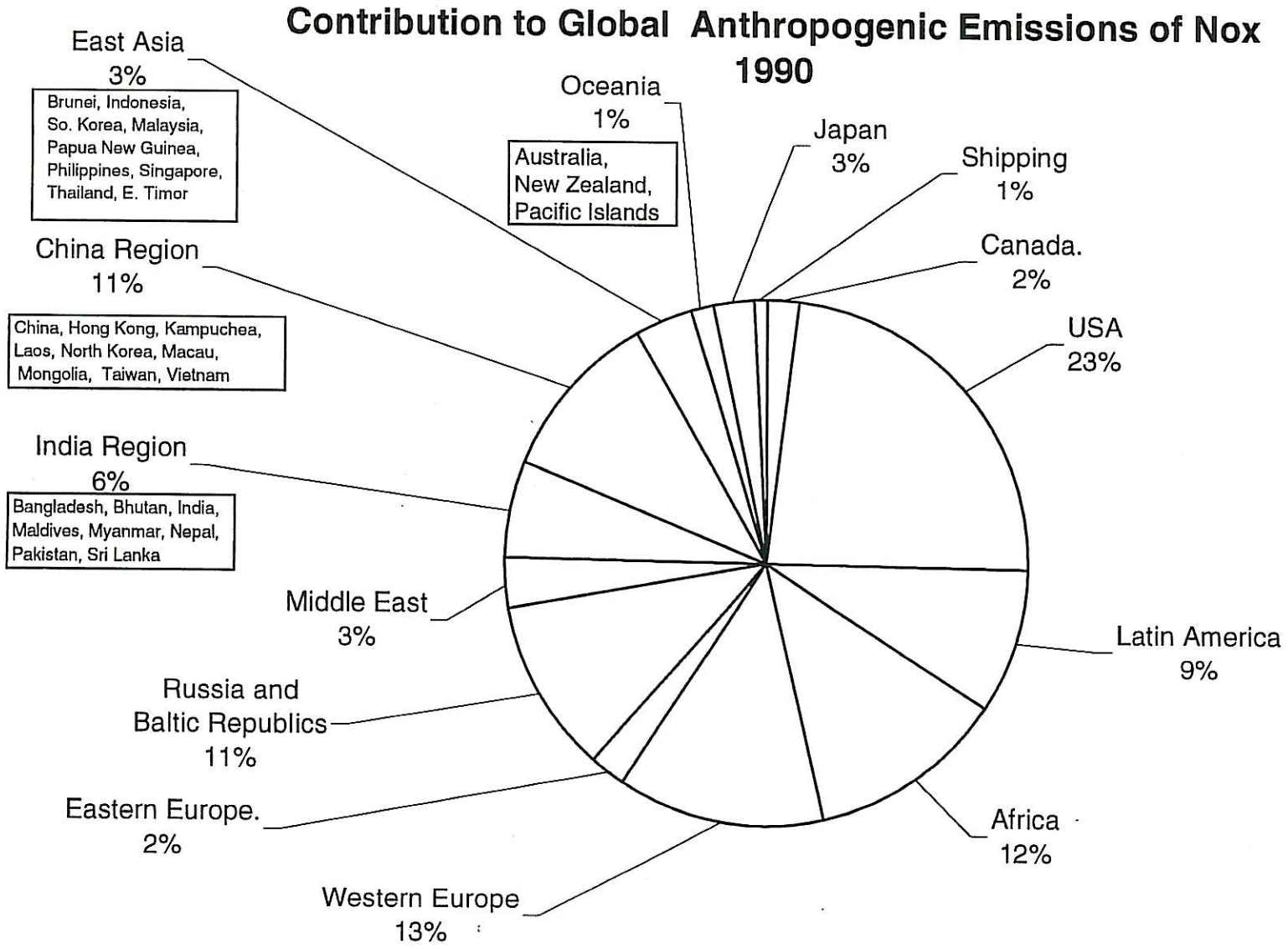
Contribution to Global Anthropogenic Emissions of Nox
1990
East Asia
3%
Brunei, Indonesia, So. Korea, Malaysia, Papua New Guinea, Philippines, Singapore, Thailand, E. Timor
Oceania
1%
Australia, New Zealand, Pacific Islands
Japan
3%
Shipping
1%
Canada.
2%
USA
23%
China Region
11%
China, Hong Kong, Kampuchea, Laos, North Korea, Macau, Mongolia, Taiwan, Vietnam
India Region
6%
Bangladesh, Bhutan, India, Maldives, Myanmar, Nepal, Pakistan, Sri Lanka
Middle East
3%
Latin America
9%
Russia and Baltic Republics
11%
Eastern Europe.
2%
Africa
12%
Western Europe
13%

Figure 1

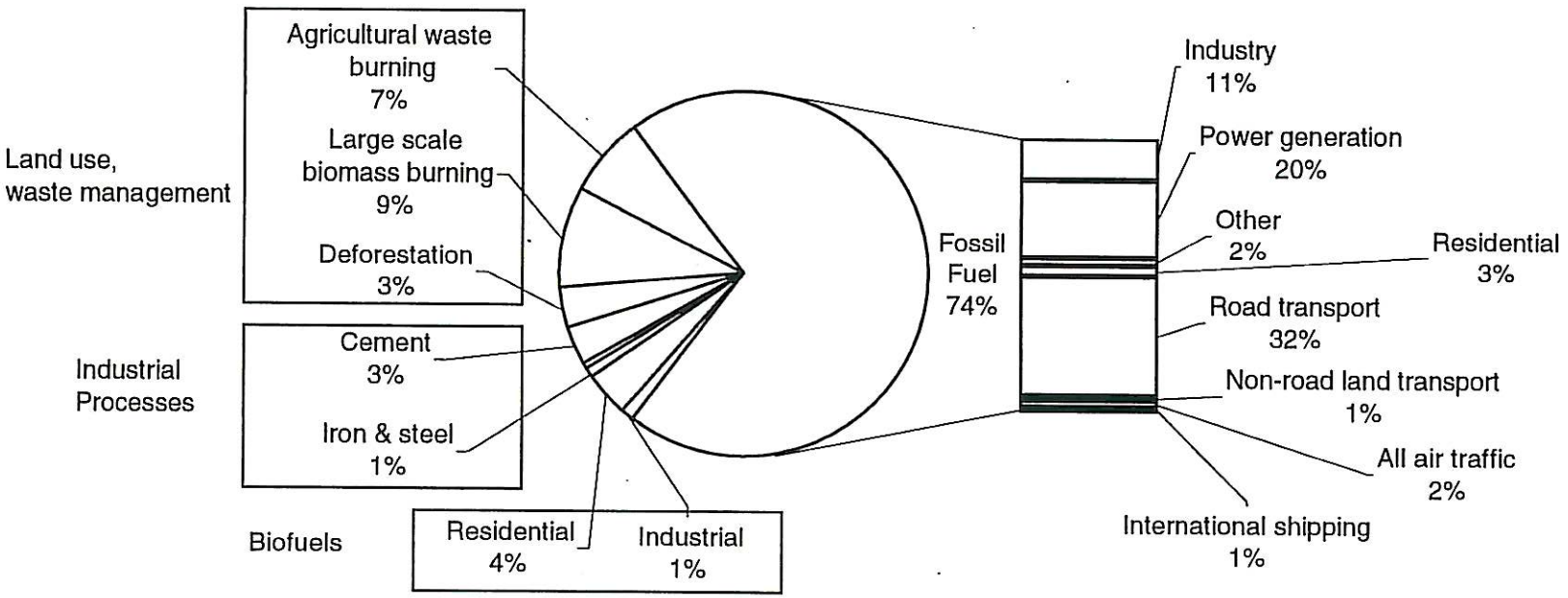
Contribution to Global Anthropogenic Emissions of NO_x
1990
Land use, waste management
Agricultural waste burning 7%
Large scale biomass burning 9%
Deforestation 3%
Industrial Processes
Cement 3%
Iron & steel 1%
Biofuels
Residential 4%
Industrial 1%
Fossil Fuel 74%
Industry 11%
Power generation 20%
Other 2%
Residential 3%
Road transport 32%
Non-road land transport 1%
All air traffic 2%
International shipping 1%

Figure 2

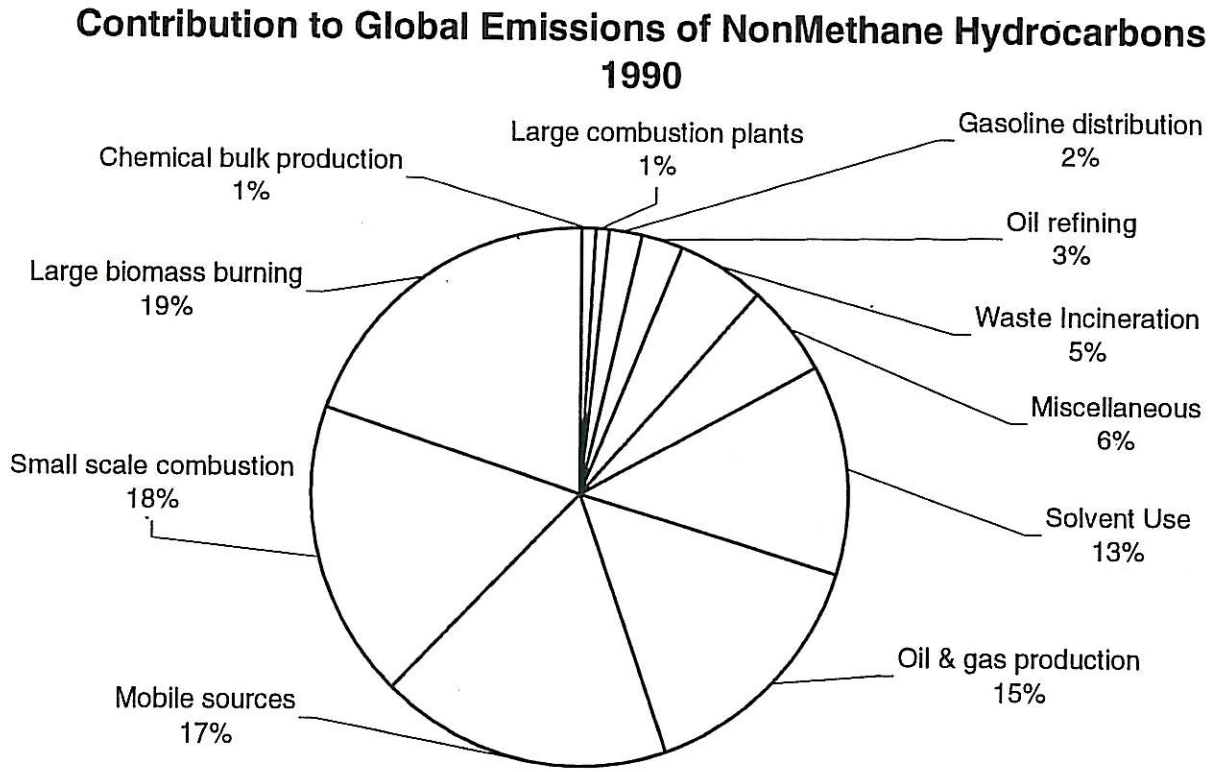
Contribution to Global Emissions of NonMethane Hydrocarbons
1990
Large combustion plants
1%
Gasoline distribution
2%
Chemical bulk production
1%
Oil refining
3%
Large biomass burning
19%
Waste Incineration
5%
Miscellaneous
6%
Small scale combustion
18%
Solvent Use
13%
Oil & gas production
15%
Mobile sources
17%

Figure 3

Contribution to NonMethane Hydrocarbon Emissions in U.S 1990

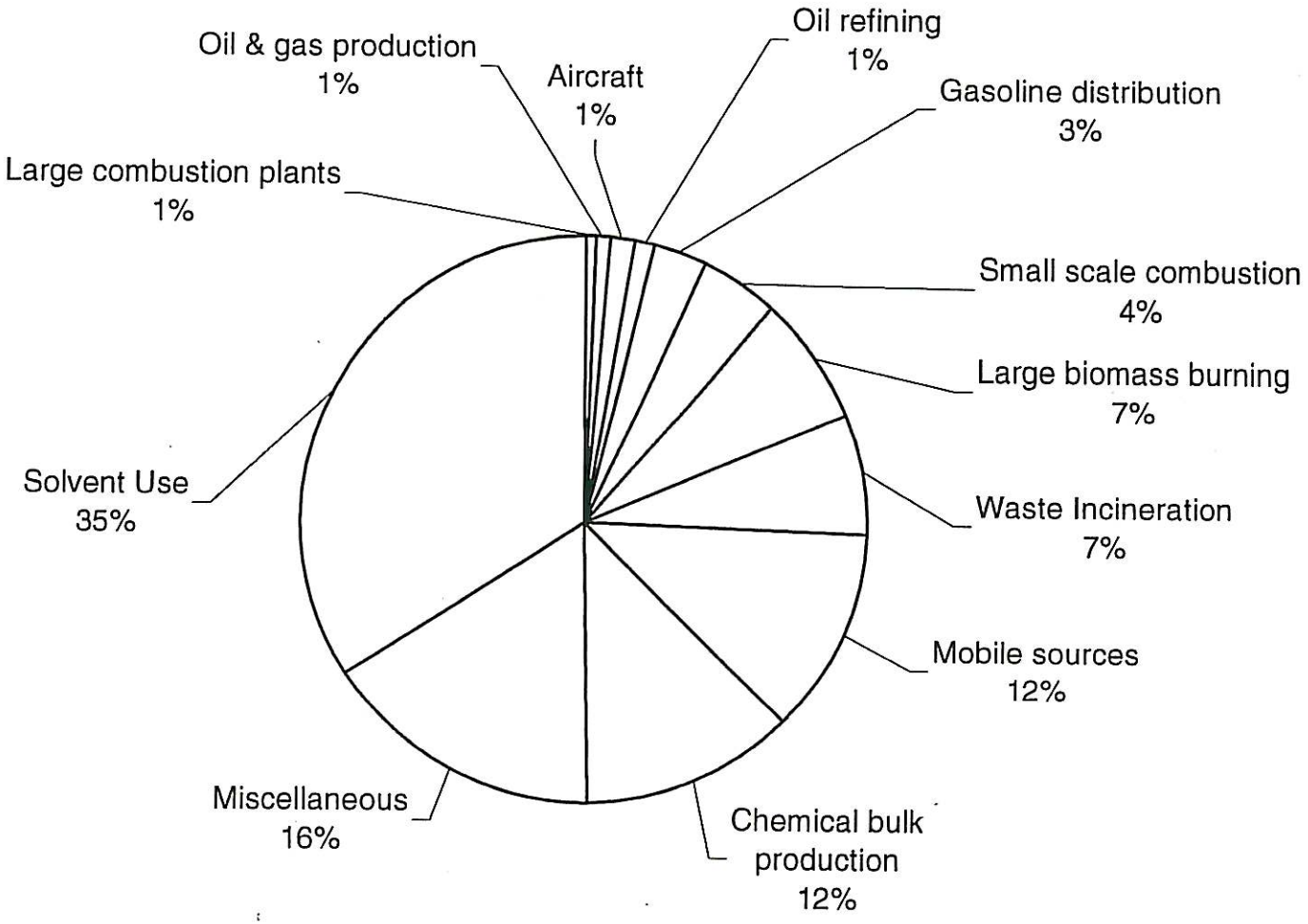

Figure 4

Contribution to Global Emissions of NonMethane Hydrocarbons 1990

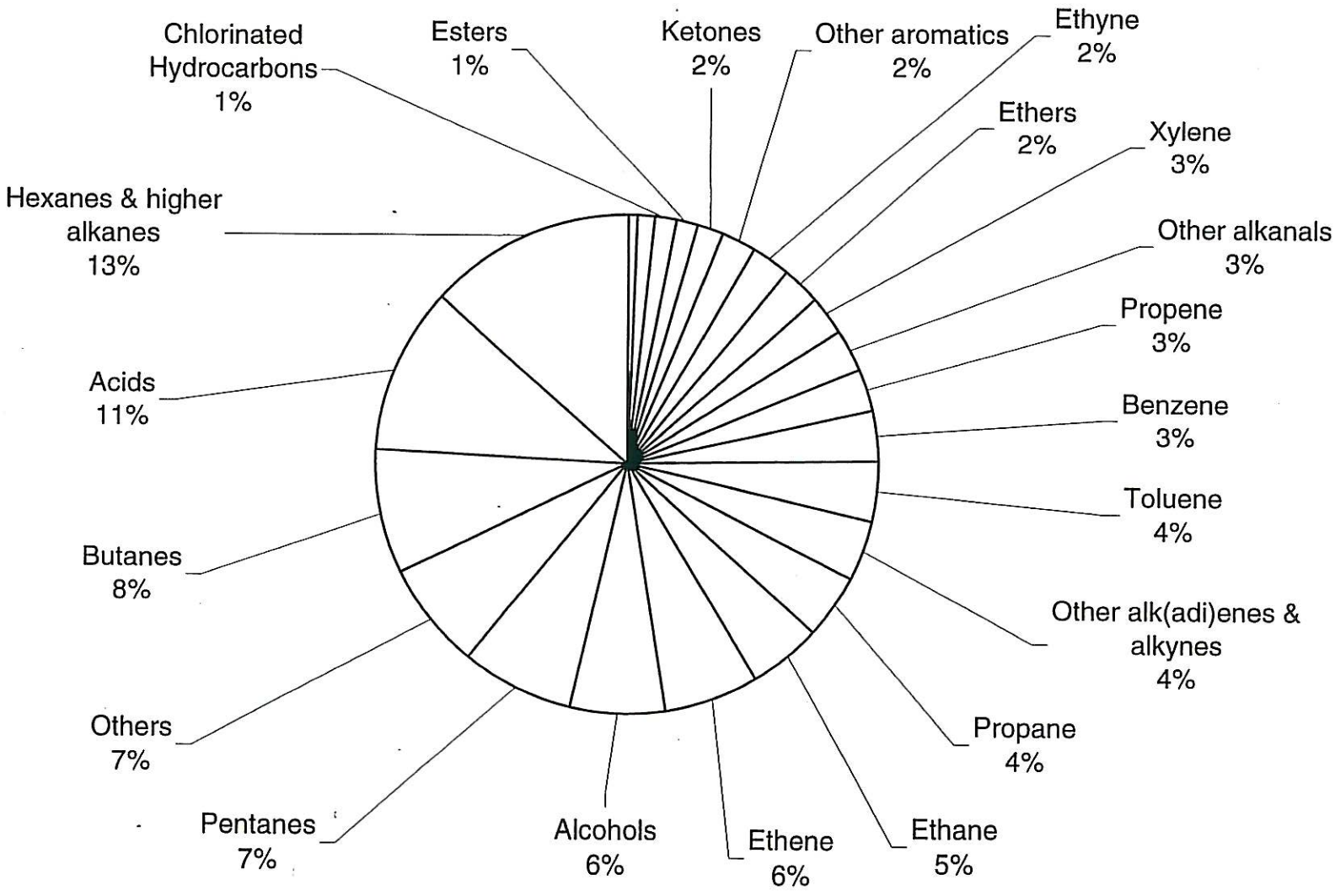

Figure 5

Contribution to Emissions of NonMethane Hydrocarbons in the US 1990

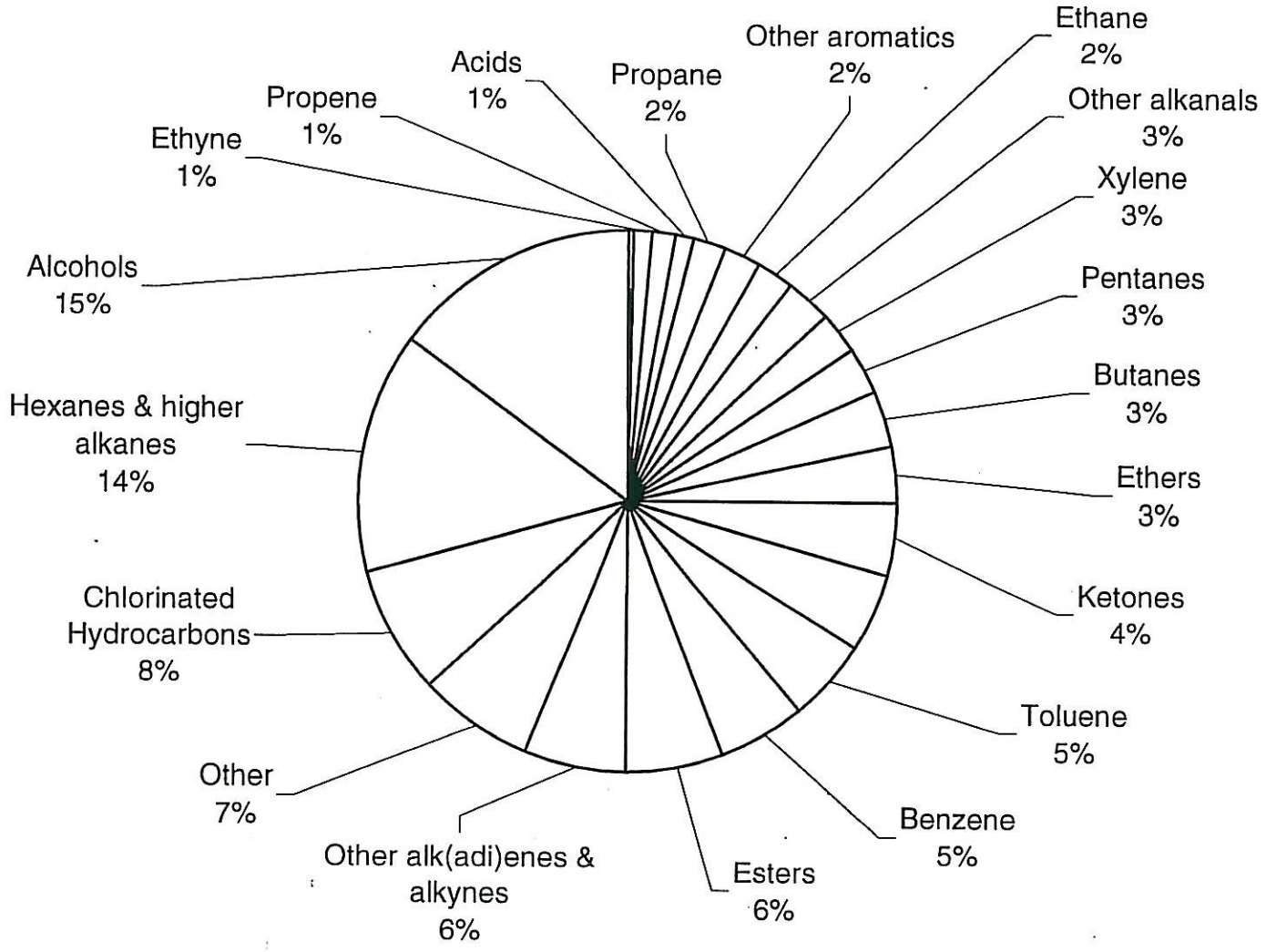

Figure 6