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Project Summary

Global Inventory of Volatile Organic Compound Emissions from Anthropogenic Sources

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As part of an effort to assess the potential environmental impacts of global climate change, the U. S. EPA is working with global atmospheric modelers to estimate the global atmospheric concentration of ozone. Atmospheric chemistry models require, as one input, an emissions inventory of reactive volatile organic compounds (VOCs). The global inventory of anthropogenic VOC emissions which has been developed and is presented in this report includes separate inventories for seven VOC reactivity classes—paraffins, olefins, aromatics, (benzene, toluene, and xylene), formaldehyde, other aldehydes, other aromatics, and marginally reactive compounds. Developing this inventory involved four major steps: (1) identify major anthropogenic sources of VOC emissions in the U.S.; (2) grouping them into categories based on relating emissions to production or consumption of the related commodity; (3) multiplying U.S. emission factors by production/consumption statistics for other countries to yield global VOC emission estimates; and (4) developing geographic distribution of global VOC emissions. Study results show total global anthropogenic emissions of about 100 million short tons* of VOCs per year, about 21% from the U.S. Fuelwood utilization and savanna burning are the largest global VOC sources, accounting about 35% of global VOC emissions.

* 1 Short ton = 0.9072 metric ton

This Project Summary was developed by EPA's Air and Energy Engineering Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Increased atmospheric concentrations of carbon dioxide (CO_2) and other relatively important trace gases [e.g., methane (CH_4), nitrous oxide (N_2O), ozone (O_3), and chlorofluorocarbons (CFCs)] have raised concerns about potential climate change among the general public and members of the scientific community. However, much uncertainty remains in the science involved in estimating global climate change. An area of greatest uncertainty is the role of atmospheric chemical reactions, including those resulting in the formation of O_3. Key factors in these reactions are the atmospheric concentrations of volatile organic compounds (VOCs) and oxides of nitrogen (NO_x). Consequently, it is important to have emissions inventories for these gases with sufficient geographic resolution, and, for the VOCs, sufficient speciation into different reactivity classes, so that O_3 concentrations in the atmosphere can be estimated.

The purpose of this research effort was to develop a global emissions inventory of

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VOCs emitted from anthropogenic sources. EPA plans to use the inventory in atmospheric chemistry models developed by I.S.A. Isaksen at the University of Oslo, in Norway. His two-dimensional model requires VOC data, speciated in five reactivity classes: (1) paraffins, (2) olefins, (3) aromatics, (4) formaldehyde, and (5) other aldehydes. Two other classes - (6) other aromatics and (7) marginally reactive compounds - were included in the inventory for comnpleteness and to ensure that the needs of other atmospheric chemistry models for geographically gridded and speciated VOC data could be accommodated. The inventory was geographically resolved within 10 by 10 degree grids.

Technical Approach

Figure 1 outlines the technical approach used to develop the global VOC inventory. The 1985 U.S. NAPAP Emissions Inventory - Version 2 was used to identify these sources.

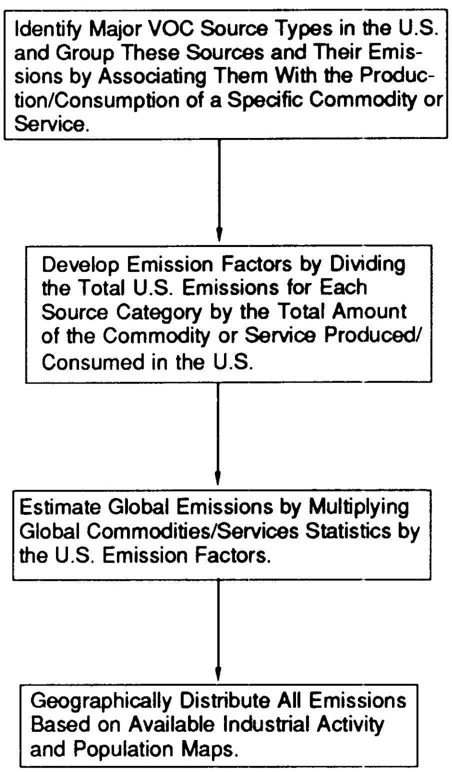


Figure 1. *Technical approach used in developing global VOC emissions inventory.*

Over 3000 different point and area sources are identified in the NAPAP inventory. Each source is included in the global inventory using various simplifying assumptions and source aggregation techniques. Biomass burning associated with land clearing (deforestation), for the creation of agricultural land and pasture, and savanna burning are not significant U.S. sources and, therefore, are not specifically included in the NAPAP inventory. However, these sources are included in the global VOC inventory because studies have shown that they are significant global sources of CO_2, and are also considered potentially significant sources of VOCs. On the other hand, although natural sources can contribute significantly to total VOC emissions in areas with substantial vegetation, developing data on these VOC emissions was beyond the scope of this project and, therefore, was not included.

The major sources of VOC emissions in the U.S. were grouped according to the types of commodities with which they are associated. For example, oil refinery heaters, catalytic cracking, and pipeline leaks represent a diverse group of VOC emission sources which are all related to crude oil. It is possible, therefore, to combine these U.S. sources and develop a relationship which describes their emissions as a function of the amount of crude oil processed in the U.S. Hereafter, groups of similar emission sources are referred to as source categories.

For each source category, the U.S. VOC estimates were divided by their associated commodity values. The resulting commodity-related emission factors, when multiplied by commodities statistics for other countries, yielded VOC emission estimates for those countries. For each category, as many as seven emission factors were developed to represent the seven VOC reactivity classes. Many sources emit all seven reactivity classes of pollutants, while other sources emit only one or two.

Concurrent with the assignment of source categories, many references were consulted in order to gather the necessary global commodities data. Publications by the United Nations (UN), the U.S. Department of Commerce, and U.S. trade organizations contained data for 195 countries.

The final step in developing the inventory was geographic distribution of the global emissions. Maps of individual countries were used to locate centers o population, industry, chemical manufacture, and petroleum refining. An atlas was used to locate the major deserts and forests on a continental basis. In general, emissions are distributed into grid cells of 10 degrees latitude by 10 degrees longitude.

Caveats

The inventory described in this document was intended to be an initial, limited effort aimed at producing the needed data within tight budget and time constraints. Many of the assumptions used in the development of the inventory clearly introduce inaccuracies but were necessary in order to meet project constraints. For instance, application of emission factors derived from U.S. data to sources in less fully developed countries is unrealistic but was necessary because emission factor data are generally unavailable for such countries. However, it was felt that relatively early production of a gridded, speciated VOC inventory would meet needs in the scientific community and would encourage the application of additional resources to improve the quality of the inventory for meeting future needs.

Results

Emissions of the seven reactivity classes are given in tons per year for each of the 648 grid cells of the globe. Results show total emissions of 120,555,486 tons of VOC per year.

The inventory is presented by source category in Table 1. The data in this table show that a relatively small number of source categories account for more than 75% of the VOC emissions included in the inventory. These source groups, listed in rank order, are:

Group	Percent of Total VOC Emissions
Fuelwood Utilization (Source Group 21)	20
Savanna Burning	16
Gasoline Storage, Consumption, Transportation, and Marketing (Source Group 4)	16
Refuse Disposal (Source Group 22)	8
Miscellaneous Emission Sources (Source Group 27)	7
Rubber, Plastics, and Other Organic Chemical Manufacture (Source Group 11)	7
Solvent Use (Source Group 12)	7
Deforestation for Agriculture (Source Group 23)	3
Total	84

TABLE 1. *Global VOC Emissions by Source Category (tons/year)*

Production/Consumption Source Category	Total	Paraffins	Olefins	Aromatics[a]	Formaldehyde	Other Aldehydes	Other Aromatics	Marginally Reactive
Fuelwood Utilization	24474369	9316136	7654339	7503543	0	31	225	92
Savanna Burning	19840168	1884816	17955352	0	0	0	0	0
Gasoline: Storage, Consumption, Transportation, Marketing	19326219	10979580	2479923	2800082	131454	53292	2881884	1
Refuse Disposal	9083206	4259054	3895003	625249	41722	33916	144009	84252
Miscellaneous Emission Sources	8781374	3660047	2747703	1722517	111401	54819	356482	128401
Rubber, Plastics, and Other Organic Chemical Manufacture	8118440	4760237	1674775	540519	39593	80470	834139	188705
Solvent Use	7968357	7218666	38372	168938	34753	0	86758	420867
Petroleum Refining	4137574	3501570	85026	52509	494568	36	3566	296
Deforestation for Agriculture	3825950	1704648	2121302	0	0	0	0	0
Surface Coating Operations	3415649	1822136	221918	1136432	1264	15	214631	19249
Managed Burning - Prescribed	2301206	1025300	1275906	0	0	0	0	0
Forest Fires	1970637	878015	1092622	0	0	0	0	0
Diesel Vehicles	1243808	967906	0	0	120953	65744	7726	81478
Other Industrial/Utility Activities	982383	512877	132045	165484	45716	14332	76158	35768
Paper Coating	795647	415609	2	374743	0	0	5291	0
Asphalt Paving	659754	315058	45634	0	0	0	299061	0
Printing/Publishing	640155	491831	11397	8858	3416	0	112589	12062
Oil and Natural Gas Production	596007	565045	13945	6533	3659	931	3775	2115
Bakeries	474610	225885	99295	51275	10392	7080	59840	20841
Aircraft Landings/Takeoffs (LTOs)	333118	83298	137380	12761	64918	24254	10505	0
Coke Production	317392	103263	125743	65604	3127	2542	10794	6315
Deforestation for Pasture	305887	136287	169599	0	0	0	0	0
Other Petroleum: Storage, Transportation, and Marketing	304593	197629	3412	95557	0	0	7990	1
Crude Oil: Storage, Transportation, and Marketing	286201	281693	0	4508	0	0	0	0
Production of Automobiles and Light Trucks	222706	107040	918	95197	51	41	19353	103
Pulp and Paper Industry	66849	41274	5368	4913	13984	73	1052	182
Paint Production	65691	26938	5649	27113	822	668	2838	1660
Distillate Fuel Oil: Storage, Transportation, And Marketing	17536	16805	0	730	0	0	0	0

[a] benzene, toluene, and xylene

Emissions of the seven reactivity classes were geographically distributed on the basis of 10° x 10° global grids. The three largest source categories and their contribution, in percentage of total emissions, to each reactivity class are shown below:

- Paraffins
  - Gasoline: Storage, Consumption, Transportation, and Marketing - 20%
  - Fuelwood Utilization - 17%
  - Solvent Use - 13%
- Olefins
  - Savanna Burning - 43%
  - Fuelwood Utilization - 18%
  - Refuse Disposal/Other - 9%
- Aromatics
  - Fuelwood Utilization - 49%
  - Gasoline: Storage, Consumption, Transportation, and Marketing - 18%
  - Miscellaneous Emission Sources - 11%
- Formaldehyde
  - Petroleum Refining - 44%
  - Gasoline: Storage, Consumption, Transportation, and Marketing - 12%
  - Diesel Vehicles - 11%
- Other Aldehydes
  - Rubber, Plastics, and Other Organic Chemical Manufacture - 24%
  - Diesel Vehicles - 19%
  - Miscellaneous Emission Sources - 16%
- Other Aromatics
  - Gasoline: Storage, Consumption, Transportation, and Marketing - 56%
  - Rubber, Plastics, and Other Organic Chemical Manufacture - 16%
  - Miscellaneous Emission Sources - 7%
- Marginally Reactive Compounds
  - Solvent Use - 42%
  - Rubber, Plastics, and Other Organic Chemical Manufacture - 19%
  - Miscellaneous Emission Sources - 13%

Fuelwood use is one of the largest source categories for emissions of olefins and aromatics. This accounts for the heavy emission rates of these VOCs from Africa and Asia. Savanna burning is the most significant source of olefin emissions and accounts for most of the high olefin emissions occurring in central Africa and South America. The high rates of emissions of paraffins, olefins and aromatics in the industrialized areas of Europe and North America, as shown in Figures 2 through 4, are due to large contributions from the gasoline, solvent use, refuse disposal and miscellaneous source categories. The "other aldehydes" reaction class is primarily emitted by industrial sources such as diesel vehicles, chemical manufacture and gasoline. For this reason, high rates c other aldehydes emissions were found t be limited to the heavily industrialized ar eas of the U.S., Japan and Europe. Th distribution of formaldehyde emissions i heavily influenced by petroleum refining Consequently, the areas of heavy formal dehyde emissions include the Middle Eas as well as the industrialized areas. The geographic distributions of other aromat ics and marginally reactive compounds generally cover the industrialized countries. The geographic distribution of total VOCs is shown in Figure 5.

The Netherlands Organization for Applied Scientific Research (OASR) recently completed a global inventory of 11 volatile organic compounds. Their study estimated that global emissions of the 11 specific VOCs were 66,700,000 tons per year. This report also estimated that total non-methane VOC emissions are roughly twice the estimate for the 11 specified compounds or 133,342,000 tons per year. Although these results are 35% above the estimate of total VOC emissions in this report, given all the data uncertainties, they are still in reasonable agreement.

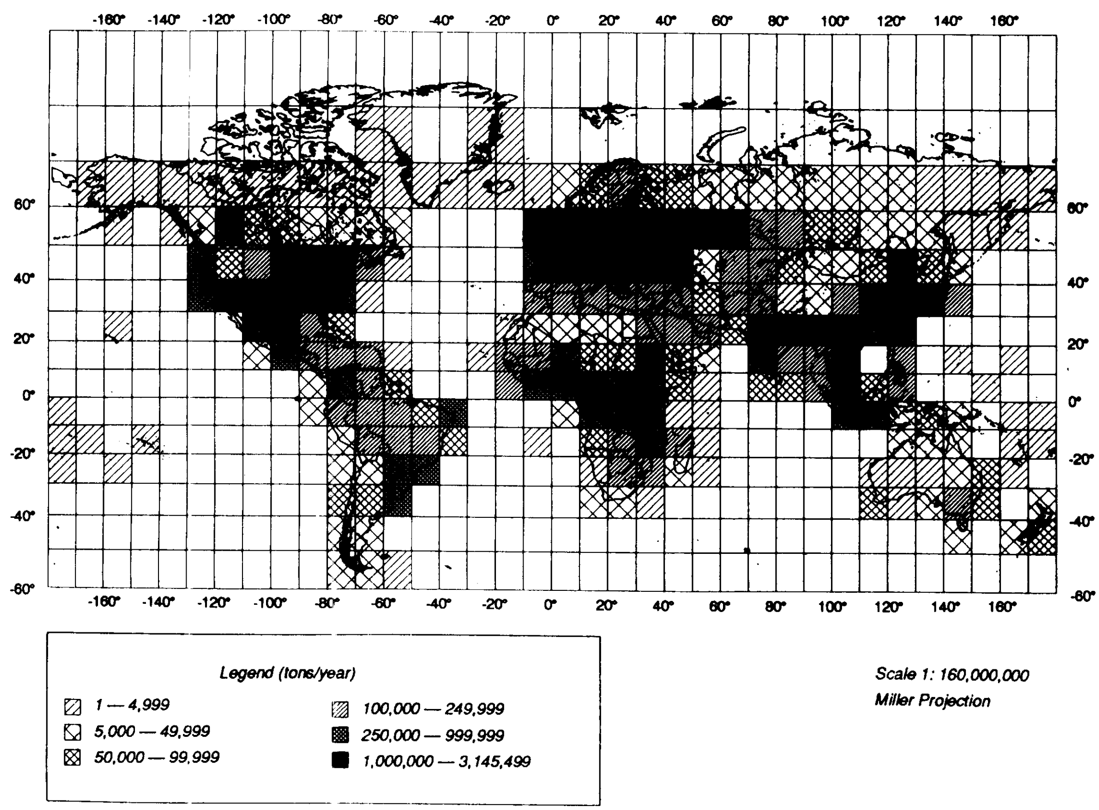
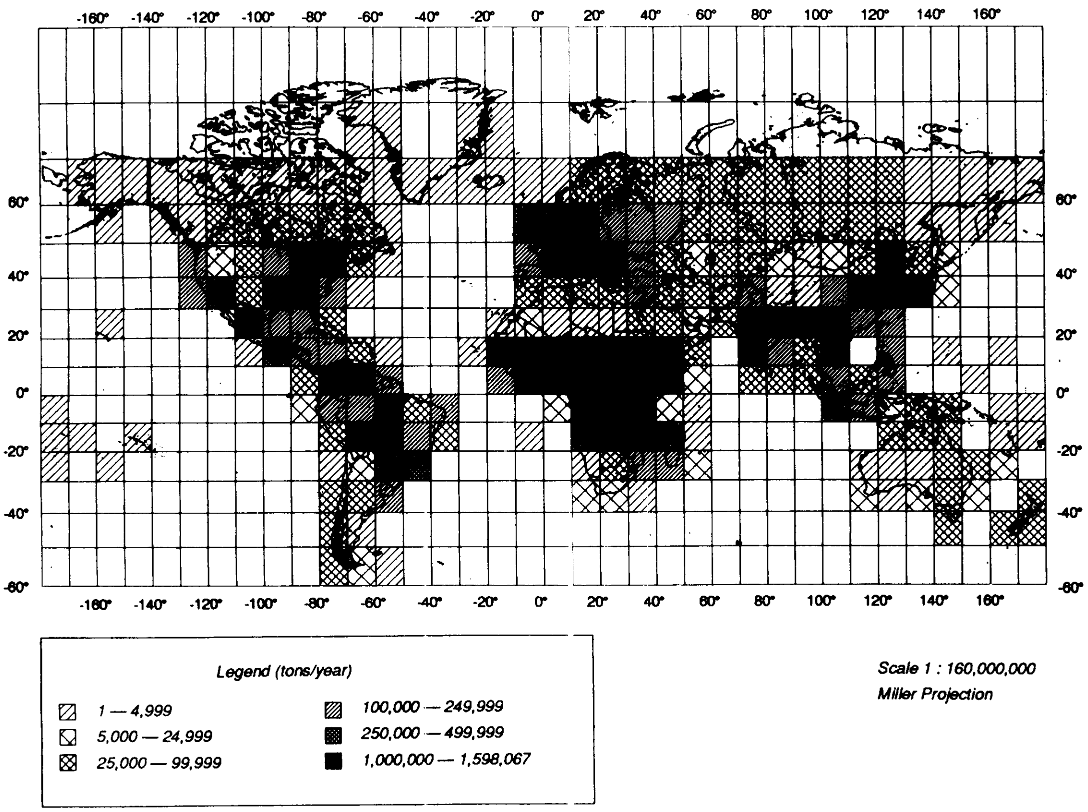
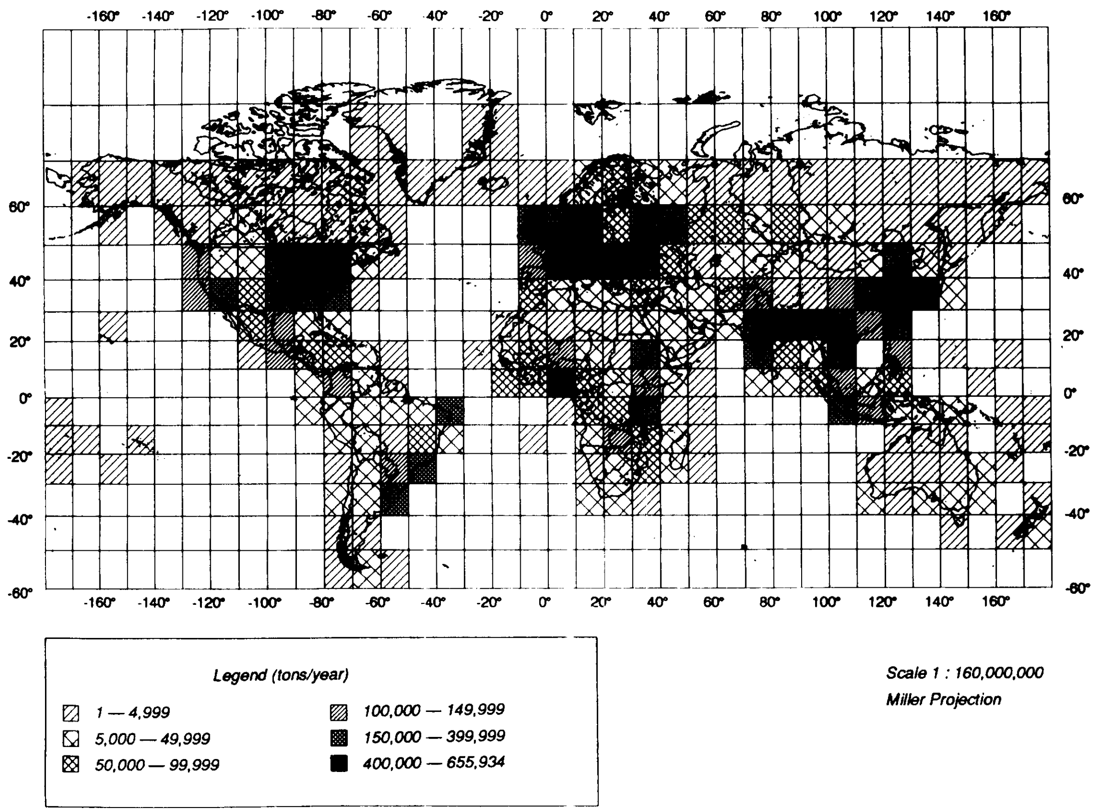


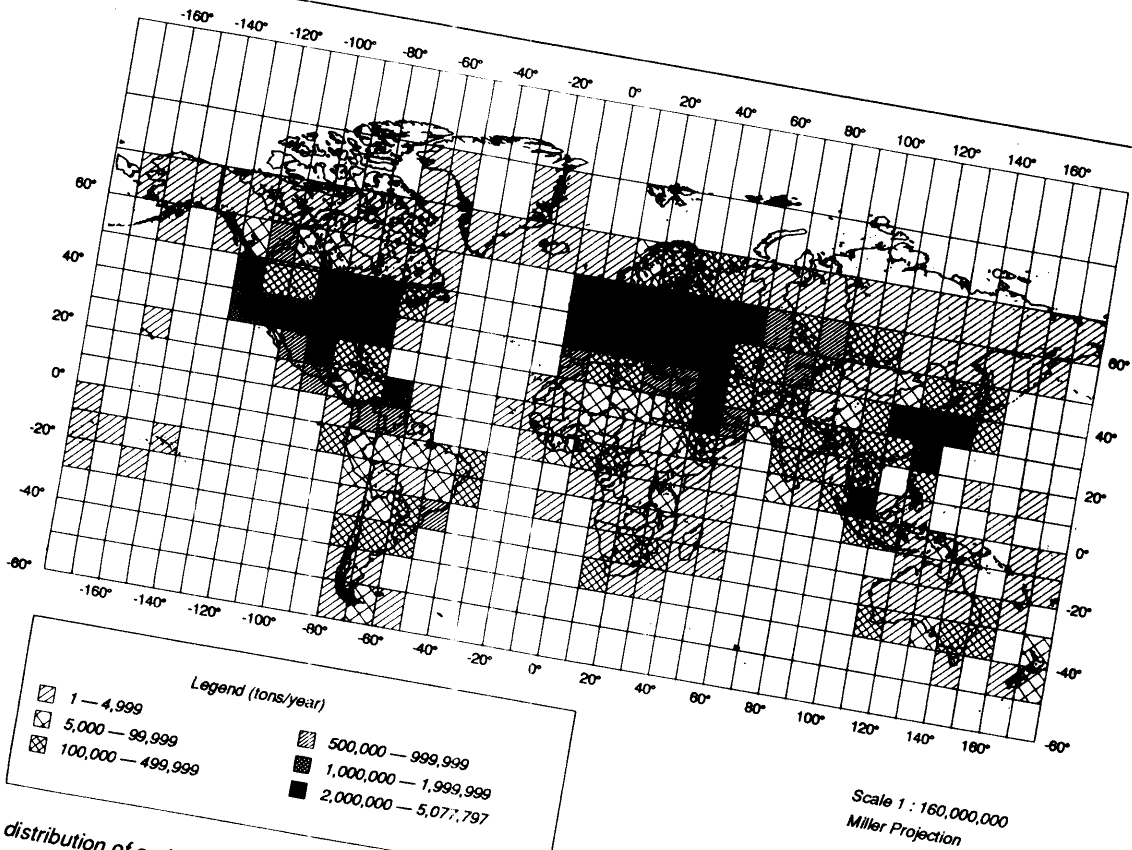
Figure 2. *Geographic distribution of emissions of paraffins.*



ure 3. Geographic distribution of emissions of olefins.



ure 4. Geographic distribution of emissions of aromatics.



5. Geographic distribution of emissions of total VOCs.

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Julian W. Jones is the EPA Project Officer (see below).
The complete report, entitled "Global Inventory of Volatile Organic Compound Emissions from Anthropogenic Sources," (Order No. PB91-161687/AS; Cost: $17.00, subject to change) will be available only from:
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