

Reconciliation and Comparison of Regional and Global Emission Inventories

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ABSTRACT

Once thought of as a local issue, air pollution is now recognized as a complex problem subject to local, regional, hemispheric, and global influences. Observations from surface sites and satellites, combined with predictions from global atmospheric models, suggest that air pollution transported between distant countries on an intercontinental scale can significantly affect the ability to achieve air quality objectives.

One obstacle that scientists face in assessing intercontinental flows of air pollution is the lack of high quality and officially-recognized emissions estimates for many parts of the world. Since 1990, the Global Emissions Inventory Activity (GEIA) has attempted to make accessible global gridded emissions estimates to support atmospheric modeling studies. Until recently, GEIA has only included a few data sets. For ozone and aerosols, almost all global air quality modeling efforts have relied on a single emissions data base, the Emissions Database for Global Atmospheric Research (EDGAR).

The purpose of this analysis is to compare emission estimates contained among various regional and international emission inventories, centering on emissions in the continental United States and to reconcile differences based on the alternate methods of emission inventory preparation.

INTRODUCTION

Once thought of as a local issue, air pollution is now recognized as a complex problem subject to local, regional, hemispheric, and global influences. Observations from surface sites and satellites, combined with predictions from global atmospheric models, suggest that air pollution transported between distant countries on an intercontinental scale can significantly affect the ability to achieve air quality objectives. To address this issue, a new international Task Force on the Hemispheric Transport of Air Pollution has been organized to assess the evidence for intercontinental transport of air pollutants in the Northern Hemisphere and the implications for future international cooperation to abate air pollution.

An international Task Force on the Hemispheric Transport of Air Pollutants (TF HTAP) has recently been organized under the auspices of the Convention on Long-range Transboundary Air Pollution

(LRTAP Convention). Under the leadership of the U.S. Environmental Protection Agency (EPA) and the European Commission's Environment Directorate, the task force is charged with assessing the evidence for the intercontinental transport of air pollutants in the Northern Hemisphere and providing assessments of its implications for future international cooperation to abate air pollution. Current ongoing projects are intended to contribute to the work of this task force by helping to improve the emissions inventories that underlie modeling analyses of intercontinental transport. More specifically, these projects will:

- compare available global emissions inventories to inventories developed at the regional scale and identify inconsistencies;
- compare available emissions inventories to satellite observations of atmospheric trace gases and aerosols; and
- facilitate the development of improved regional and global emissions inventories for wildfires and agricultural burning.

This work is being conducted through an existing cooperative agreement with the Center for Air Pollution Information and Trends Analysis (CAPITA) at Washington University, St. Louis, with advice and assistance from collaborating EPA and NASA staff. The tools and data produced in the effort will be publicly available through the web portal of the Networked Environmental Information System for Global Emissions Inventories (NEISGEI), which is supported under the cooperative agreement. Findings were presented at TF HTAP workshops in October 2006 and January 2007 and incorporated into TF HTAP assessment plans.

In addition to supporting the TF HTAP, these projects will provide useful products for national, state, and local air quality managers who must assess the impacts of intercontinental transport and emissions from wildfires and agricultural burning on local air quality in the context of air quality forecasting and control strategy development.

This document and associated analysis focuses on the reconciliation of global inventories developed using "top down" methods with regional inventories developed using localized "bottom up" methods for the domain covering the continental United States. This product will have an immediate impact on the development of TF HTAP's work plan, providing insights concerning the uncertainty associated with existing inventories and identifying needed improvements in the emission estimates. The contribution will improve the TF HTAP's overall assessment and, thereby, contribute to the foundation for future international policies related to intercontinental transport.

One obstacle that the TF HTAP faces in assessing intercontinental flows of air pollution is the lack of high quality and officially-recognized emissions estimates for many parts of the world. Since 1990, the Global Emissions Inventory Activity (GEIA) has attempted to make accessible global gridded emissions estimates to support atmospheric modeling studies. Until recently, GEIA has only included a few data sets. For ozone and aerosols, almost all global air quality modeling efforts have relied on a single emissions data base, the Emissions Database for Global Atmospheric Research (EDGAR), developed by a consortium of institutes in the Netherlands.

The EDGAR inventory is developed using a uniform methodology for the entire globe and is reported on a 1x1 degree grid. As a result, EDGAR data is not consistent necessarily with more spatially resolved and official emissions estimates generated at a national level, such as the U.S. National Emissions Inventory (NEI) or the EMEP inventory, which consists of data provided by each of the national governments in Europe. A recent comparison of EDGAR data to optimal estimates of mobile source emissions for the United States found large discrepancies in the national emissions totals

and directionally different temporal trends. To better understand the intercontinental flow of air pollutants, it is important to compare, evaluate, and where possible resolve the spatial and temporal differences between these emissions inventories developed at different scales.

The U.S. Environmental Protection Agency prepares a detailed emission inventory of the United States every three years. This inventory is called the National Emission Inventory (NEI) and is prepared using “bottom up” methods, activity, and emission factors at a county or State level. This NEI is used to support EPA’s photochemical modeling, as well as a variety of other types of air quality studies and analyses performed by EPA and the States. The EPA has completed a final version of the 2002 NEI as of February 2006.

The purpose of this analysis is to compare emission estimates contained between EDGAR and NEI regional and international emission inventories, centering on emissions in the continental United States and to reconcile differences based on the alternate methods of emission inventory preparation.

REGIONAL AND GLOBAL EMISSIONS INVENTORIES

Acquired Emissions Inventories

Our first task was to obtain available regional and global gridded emissions inventories to produce comparable data sets. The original effort focused on obtaining the following available inventories: EDGARv32 1990 and 1995, EDGAR 32 Fast Track 2000; U.S. National Emissions Inventory 2002; Canadian National Pollutant Release Inventory 2002; Mexican National Emissions Inventory 1999; and EPA’s ICAP trans-Pacific emissions inventory 1999/2001. Other available inventories, such as the EMEP inventory for Europe, may be addressed in future analyses and once the domain of interest has expanded beyond North America. For this paper, only inventories used in the comparison are discussed in more detail below.

Emission Database for Global Atmospheric Research (EDGAR)

The Emission Database for Global Atmospheric Research (EDGAR) project is a comprehensive task that has been carried out jointly by the National Institute for Public Health (RIVM) and the Netherlands Organization for Applied Scientific Research (TNO). It combines information on many different anthropogenic emission sources and acts in practice as a reference database for many global applications. EDGAR inventories have recently been upgraded in three phases. Each phase has built upon the last with improvements to temporal, spatial, and activity data. Additionally, more pollutants have been added to account for international agreements and consultation analyses.

EDGAR 2.0

EDGAR 2.0 provided global annual emissions for 1990 of greenhouse gases CO₂, CH₄ and N₂O and precursor gases CO, NO_x, NMVOC and SO₂, both per region and on a 1x1 grid for all anthropogenic sources. Similar inventories were compiled for a number of CFCs, halons, methyl bromide, and methyl chloroform. In the follow-up project the database was extensively validated and an uncertainty analysis was carried out. Most of the applications of EDGAR 2.0 over the last couple of years are model studies, but EDGAR data are also extensively used for policy applications for which emissions data on country level were calculated with the EDGAR information system.

EDGAR 3.2/3.3

EDGAR 2.0 was improved to EDGAR 3.2 which included an update and extension from 1990 to 1995 for all gases and extended the time series for direct greenhouse gases CO₂, CH₄ and N₂O to 1970-1995. This project also added 1970-1995 emissions of the new 'Kyoto' greenhouse gases HFCs, PFCs, and SF₆.

EDGAR 32 Fast Track 2000

The EDGAR 32FT2000 dataset contains emissions for 2000 on a gridded per country basis for the direct greenhouse gases and air pollutants covered by EDGAR 3.2. These are based on most recent activity data available by each domain and allocated by source category using EDGAR 3.2 distribution ratios. For gridded emissions of large-scale biomass burning four variants have been compiled.

Activity data for EDGAR datasets were mostly taken from international statistical data sources and emission factors were selected mostly from international publications to ensure a consistent approach across countries. Uncertainty in these data sets is caused by the limited accuracy of international activity data used and in particular of emission factors selected for calculating emissions on a country level. However, since methods used are comparable with IPCC methodologies and global totals comply with budgets used in atmospheric studies and the data were based on international information sources, this dataset provides a sound basis for global comparability.

The EDGAR database defines source categories following the definition of IPCC source categories 1 to 6:

- Fossil fuel (EDGAR category 'F');
- Biofuel (EDGAR category 'B');
- Industrial processes (EDGAR category 'I');
- Agriculture (EDGAR category 'L');
- Biomass burning (EDGAR category 'L');
- Waste handling (EDGAR category 'W');
- Production and use of halocarbons and other fluorinated gases (EDGAR category 'H'); and
- Other (EDGAR category 'F').

More detail on the sub-classification within each of these EDGAR categories is provided in later sections.

Intercontinental Transport and Climatic Effects of Air Pollutants (ICAP)

As part of EPA's efforts to investigate the urgent issue of the relationship between air pollution and global climate change, the Intercontinental transport and Climatic effects of Air Pollutants (ICAP) project was launched in 2001. The goal of ICAP was to provide scientifically sound information leading toward developing integrated control strategies to benefit both regional air quality and climate.

Phase I of ICAP established a better scientific foundation to address the linkage between climate change and air pollution and issues related to intercontinental transport of criteria pollutants. An advisory committee was formed and a workshop was held with leading scientists in the fields of air

pollution, climate change and relevant issues to consult with the project investigators with the goal to report and discuss the state of the science due to rapid expansion and progress in the field. The ICAP team conducted major activities to update emissions inventories and to characterize modeling concepts relevant to regional and global chemistry transport.

The objective of Phase II of ICAP was to conduct an assessment of long-range transport and impacts on the regional climate. Within this objective three issues were investigated: (1) the role of anthropogenic emissions originating from outside North America in U.S. air quality and the global distribution of air pollutants; (2) the role of anthropogenic emissions from the U.S. and other developed countries in determining air quality in other regions; and (3) the contributions of important source categories (e.g., biomass burning, utility sector, transportation sector) and their pollutant emissions (e.g., ozone and PM precursors, black carbon, methane) to regional air quality and climate.

In addressing these objectives, the ICAP team utilized emission inventories from a variety of sources to conduct their trans-Pacific air quality simulations. From the EPA, the National Emission Inventory (NEI) 1999 was used to represent anthropogenic emissions from stationary area, nonroad, and onroad mobile source categories. During the timeframe of the analysis, EPA released its NEI 2001 inventories and for the transport of mercury and dust, the ICAP team upgraded its point source inventory for the U.S. to include these emissions. In this analysis, the ICAP inventories are represented with NEI 1999 data.

U.S. EPA National Emission Inventory (NEI)

The EPA's Emission Inventory and Analysis Group prepares a national database of air emissions information with input from numerous State and local air agencies, from tribes, and from industry. This database contains information on stationary and mobile sources that emit criteria air pollutants and their precursors, as well as hazardous air pollutants (HAPs). The database includes estimates of annual emissions, by source, of air pollutants in each area of the country, on an annual basis. The NEI includes emission estimates for all 50 States, the District of Columbia, Puerto Rico, and the Virgin Islands. Emission estimates for individual point or major sources (facilities), as well as county level estimates for area, mobile and other sources, are available currently for years 1990 and 1996 through 2002 for criteria pollutants, and for years 1999 and 2002 for HAPs. A final version of the 2002 NEI was posted in February 2006.

The NEI includes emissions from various ozone and particulate matter precursors including volatile organic compounds (VOCs), carbon monoxide (CO), nitrogen oxides (NO_x), Sulfur dioxide (SO₂), particulate matter (PM₁₀ and PM_{2.5}), and ammonia (NH₃).

Data from the NEI are used for air dispersion modeling, regional strategy development, regulation establishment, air toxics risk assessment, and tracking trends in emissions over time. For emission inventories prior to 1999, criteria pollutant emission estimates were maintained in the National Emission Trends (NET) database and HAP emission estimates were maintained in the National Toxics Inventory (NTI) database. Beginning with 1999, criteria and HAP emissions data were prepared in a more integrated fashion in the National Emission Inventory (NEI), which takes the place of the NET and the NTI.

The NEI database defines three classes of criteria air pollutant sources:

- Point sources - stationary sources of emissions, such as an electric power plant, that can be identified by name and location. A "major" source emits a threshold amount (or more) of at least

one criteria pollutant, and must be inventoried and reported. Many states also inventory and report stationary sources that emit amounts below the thresholds for each pollutant.

- Area sources - small point sources such as a home or office building, or a diffuse stationary source, such as wildfires or agricultural tilling. These sources do not individually produce sufficient emissions to qualify as point sources. Dry cleaners are one example, i.e., a single dry cleaner within an inventory area typically will not qualify as a point source, but collectively the emissions from all of the dry cleaning facilities in the area may be significant and therefore must be included in the inventory.
- Mobile sources - any kind of vehicle or equipment with a gasoline or diesel engine; airplane; or ship.

As the focus of this analysis is the reconciliation of regional and global inventories to the U.S. continental domain, the final 2002 NEI will be considered the control dataset and will be the basis of all presented comparisons.

Availability and Format of Inventories

Availability of Data

Each of the data sets identified in the section above was publicly available via web access or FTP download. Once the data were obtained from their native source, we compared emission summaries provided with documentation on each data set to the aggregate of the raw data themselves to ensure that levels of emissions were consistent between data and documentation. Upon receipt of these data, we documented the format and major source coverage of the emission inventory data sets.

Reformat of Data

When necessary, the obtained inventories were further converted from their native formats to a format with common chemical speciation, source classifications, spatial coordinate systems, and temporal and spatial resolution. In particular, as most of these data were available annually in country/sector 1x1 degree latitude-longitude projection for each of the pollutants of interest (CO, NO_x, SO₂, NMVOC), this projection was used as the basis for comparisons in this paper.

The final 2002 U.S. NEI, the inventory to which the comparisons are being made, was obtained from the U.S. EPA in annual, county or facility-level format. The emissions summaries presented in this report for both the NEI 2002 and ICAP NEI 1999 are based on 1x1 degree aggregations of emissions either using facility specific coordinates or county level centroids to cite emissions within a latitude-longitude cell.

Scale of Data

EDGAR aims at primarily serving global atmospheric models and policy analysts at the regional or country level. For global models the present spatial resolution of 1x1 degree is noted to be quite sufficient. Other sources of emissions gathered for this analysis retain lower level geographic distribution as their development is based on “bottom up” methods using activity and emission factor data as the most detailed level of aggregation. Although many of the EDGAR sources are also based on “bottom up” calculations, these data are not made available without permission. For this analysis,

therefore, we have chosen to retain the 1x1 degree of geographic allocation and have scaled the more refined inventories accordingly.

Figure 1 presents the 1x1 degree domain in which this analysis was conducted. The domain covers all of the contiguous United States and the District of Columbia and is bounded at 24 degrees latitude and -126 degrees longitude to 50 degrees latitude and -66 degrees longitude.

Source Comparability

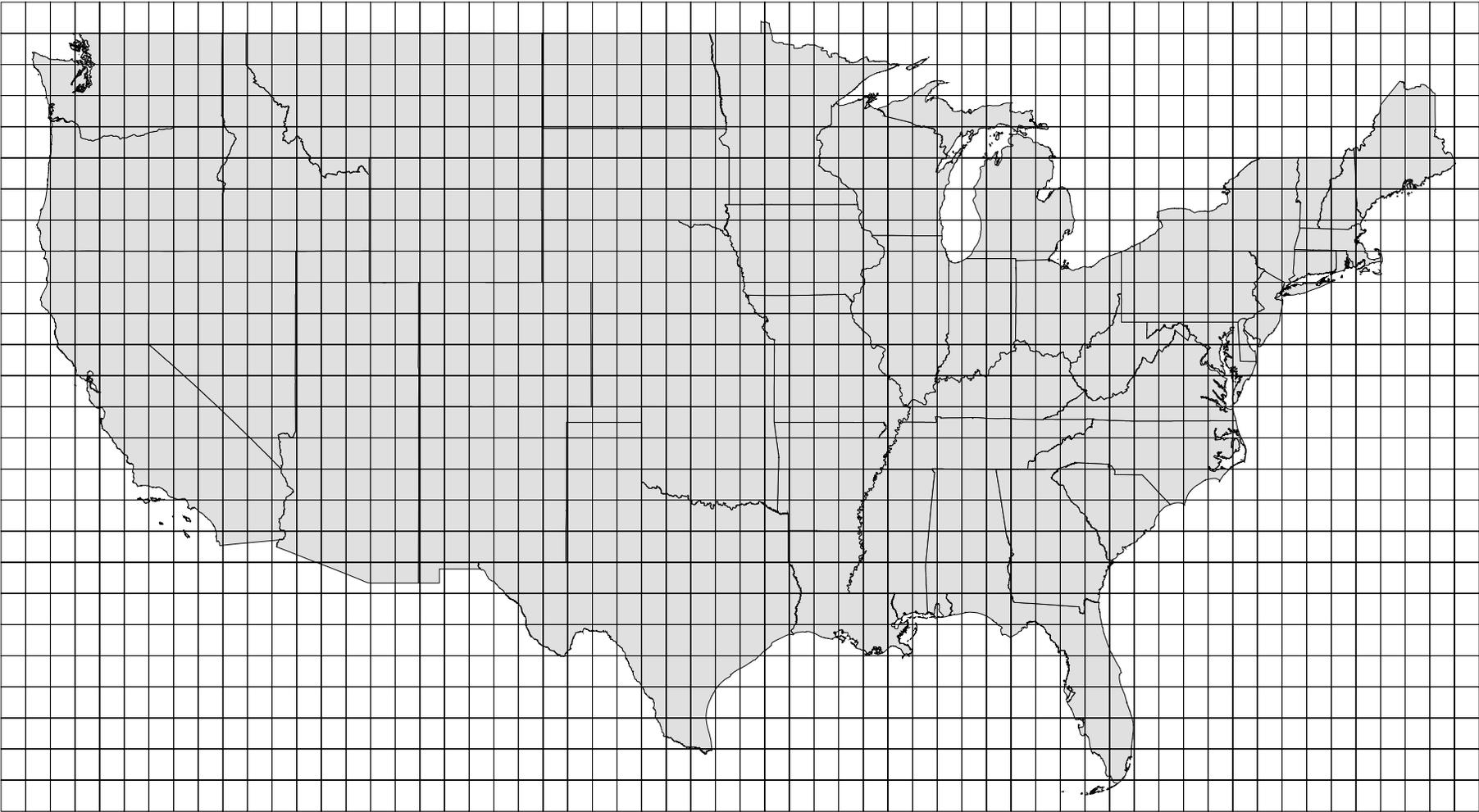
Source category codes are the building blocks upon which an emissions inventory is initially structured. These codes are used to represent the individual or aggregate processes or functions which are associated with an industry, activity, or facility type and allow the assignment of emission factors, temporal and spatial surrogates, speciation profiles, or other aggregation schemes by which to compare one data set to another.

Each of the inventories identified above uses one or more source category classification schemes to identify emission generating processes. Much like the rescaling of data to the 1x1 degree projection, the EDGAR database is based on an aggregated source classification structure. For this reason, we have chosen to represent each of the emission inventories used in this analysis to meet the aggregation scheme of EDGAR. Table 1 below identifies the major source types in which the EDGAR emissions are binned.

To match the other emission sets to the same source categorization as the EDGAR files, we conducted an exercise to link the EPA SCC-Tier structure to the aggregation scheme in EDGAR. The results of that matching are presented in Appendix A of this report. Although we have made every effort to match these category classifications between the various data sets, this correlation is not always exact and therefore individual source categories, as well as total emissions from all categories within a grid cell, are taken into account when developing comparisons from these files.

Figure 1. 1x1 degree representation of United States domain.

(50,-66)



(24, -126)

Table 1. EDGAR Source Classification Codes.

| Standard EDGAR 3 source reporting categories | | |
|---|-------|--|
| For a detailed definition of the corresponding IPCC categories see the following documents, available on the web: | | |
| IPCC 1997 Inventory Guidelines, Vol I, Reporting Instructions, Ch. 1 | | |
| http://www.ipcc-nggip.iges.or.jp/public/ghl/guidelin/ch1ri.pdf | | |
| UNFCCC Common Reporting Format Guidelines | | |
| http://unfccc.int/resource/docs/cop5/07.pdf | | |
| Standard EDGAR 3 source reporting categories for fossil fuel, biofuel and industrial processes | | |
| IPCC code | EDGAR | Fossil fuel use |
| 1A2 | F 10 | Industry (excluding coke ovens, refineries, etc.) |
| 1A1a | F 20 | Power generation (public and auto; including cogeneration) |
| 1A1b,c | F 30 | Other transformation sector (refineries, coke ovens, gas works etc.) |
| 1A4 | F 40 | Residential, Commercial and Other sector (RCO) |
| 1A3b | F 51 | Transport Road |
| 1A3c,d-ii,e | F 54 | Transport Land Non-road (Rail+Inland water+pipeline+Non-specified) |
| 1A3a | F 57 | Transport Air (Domestic+International) |
| 1A3d-i | F 58 | Transport International Shipping (marine bunkers) |
| 1A2 or 2B,C | F 60 | Non-energy use and chemical feedstocks (CO2 only) |
| Fossil fuel production and transmission | | |
| 1B1a | F 70 | Coal production+ (incl. CH4 recovery) |
| 1B2a,c | F 80 | Oil production, transmission and handling |
| 1B2b | F 90 | Gas production and transmission |
| - | F 95 | Fossil fuel fires |
| Biofuel combustion | | |
| 1A2 | B 10 | Industry (excluding coke ovens, refineries, etc.) |
| 1A1a | B 20 | Power generation (public and auto; including cogeneration) |
| 1B1b | B 30 | Charcoal production |
| 1A4 | B 40 | Residential * |
| 1A3b | B 51 | Transport Road |
| * Only residential emissions; commercial and other sector have zero biofuel emissions. | | |
| Industrial processes (incl. non-industry process sources) | | |
| 2C1 | I 10 | Iron & Steel |
| 2C3,5 | I 20 | Non-ferro metals |
| 2B | I 30 | Chemicals |
| 2A1 | I 40 | Building materials |
| 2D1 | I 50 | Pulp & Paper |
| 2D2 | I 60 | Food |
| 3 | I 70 | Solvent use/Miscellaneous |
| 1A3b | I 80 | Transport evaporation (NMVOC only) (already included in F51) |
| 2-other | I 90 | Miscellaneous industry |
| Standard EDGAR 3 source reporting categories for agriculture, biomass burning and waste handling: | | |
| Agriculture/biomass burning (landuse) | | |
| 4D | L 10 | Arable land (fertiliser use) |
| 4C | L 15 | Rice cultivation |
| 4A | L 20 | Animals (enteric fermentation) |
| 4B | L 30 | Animal waste management (confined N2O; all CH4) |
| 5A1 | L 41 | BB-Deforestation |
| 4E | L 42 | BB-Savanna burning |
| 4F | L 43 | BB- Agricultural waste burning |
| 5A2,3 | L 44 | BB-Vegetation fires (temperate) |
| 5B1 | L 45 | BB-Deforestation-post burn effects (CO2+N2O) |
| 4D | L 50 | Crop production (N) |
| 4B | L 60 | Animal waste (deposited on soil - N2O) |
| 4D | L 71 | Atmospheric Deposition |
| 4D | L 75 | Leaching and Run-off |
| Waste handling | | |
| 6A1,2 | W 10 | Landfills+ (incl. CH4 recovery) |
| 6D | W 15 | Humans/pets [p.m.] |
| 6B1,2 | W 20 | Waste Water Treatment+ (incl. CH4 recovery) |
| 6B2 | W 30 | Human Wastewater Disposal |
| 6C | W 40 | Waste incineration (non-energy) |
| 6A3 | W 50 | Miscellaneous waste handling (hazardous waste) |

Source: <http://www.mnp.nl/edgar/documentation/definitions/#tcm:32-14018>

Purpose of Use

Regulatory

Emission inventories in North America were originally developed to identify, track, and remedy air quality problems around the largest cities and metropolitan areas in the country. These inventories were largely prepared for individual industrial and localized area and mobile sources and methods; factors and calculations were transferred to similar industries and categories when no measurement or source data were available. Typically, these inventories captured the largest emitters in the geographic area and allowed policy makers to assign control strategies and reduction options to these sources with the intent to reduce emissions and improve air quality.

As these inventories became more robust in both their coverage and source data, linkages between source types, their effluent pollution production, and air quality were identified. These linkages became the precursor to today's emissions and air quality models and have been used to further the science in forecasting emission change and its impact on air quality.

Today's global inventories track and maintain emissions for close to ten thousand different source categories for hundreds of air pollutants over numerous temporal and geographic scales making it far from uncomplicated in their preparation and use. Additionally, once used primarily for local-scale impacts and tracking, these data sets have become necessary for policy makers and researchers alike to simulate transport of air pollutant emissions on regional, national, and international levels. However, the preparation of these inventories can be unique to individual areas and inconsistent within regional and international airsheds.

Research

The United Nations Framework Convention on Climate Change sets an overall framework for intergovernmental efforts to tackle the challenge posed by climate change. It recognizes that the climate system is a shared resource whose stability can be affected by industrial and other emissions of carbon dioxide and other greenhouse gases.

The Convention calls on Parties to promote and cooperate in research and systematic observation of the climate system, including through support to existing international programs and networks. In doing so, the Convention commits Parties to cooperate to improve the capacities of developing countries to participate in research and systematic observation.

With the participation of multiple countries in international collaborations and resolutions, emission inventories have recently been reviewed and prepared with more scientific appraisal. This adjustment of purpose has created the need for these data to be made more complete, accurate, timely, transparent, and affordable to science bodies in need of their use. This adds an elevated level of responsibility on inventory developers to maintain the metadata and calculate the uncertainty on higher levels of aggregation.

As researchers collaborate on regional and international climate change research programs, they inform other participants on their current activities to address their research needs, including on-going efforts to enhance the capacity and participation of developing countries in climate change research.

Furthermore, noted is the need for enhancing two-way communication and cooperation between individuals and regional and international climate change research programs, and agreement to explore how scientists might facilitate a more effective dialogue between themselves and these programs.

The EDGAR inventories obtained for this study have elsewhere been used to provide activity and emission factors to the global modeling analyses. EDGAR inventories are also used by many modelers, either as EDGAR inventories or as specific GEIA inventories, which have been developed to support atmospheric modeling work.

Additionally, beyond the research applications of the EDGAR inventories, these data sets have been used for assessing annual trends in global and regional emissions of greenhouse gases and ozone depleting compounds.

Comparison of Inventories

A number of recent analyses have been conducted with the purpose of comparing, either in whole or in part, various regional and international emission inventories in efforts to reconcile these data on temporal and spatial scales. Continuing with these efforts, we are making additional strides to compare U.S. EPA's National Emissions Inventories (NEI) with the EDGARv32 inventories with the objective of qualitatively and quantitatively reconciling the two to allow the science of international transport to benefit from the results.

In the remainder of this document, we have developed source and pollutant specific comparisons of the EDGARv32 and NEI emission inventories for the precursor pollutants of SO₂, NO_x, CO, and NMVOC. Focus is on anthropogenic source emissions on both total and source specific scales. Since the most prevalent anthropogenic source types contributing to intercontinental transport have been shown to be those of an elevated nature, we have limited the source specific comparisons to those categories with high levels of elevated source emissions. A list of those categories, using the EDGAR classification scheme, is presented in Table 2.

All Source Types

Summary statistics related to the NEI and EDGARv32 emission inventories for grid cells represented in the domain in Figure 1 have been prepared for annual anthropogenic emission estimates and are presented in this section. As is seen in these summaries and figures, there are both favorable correlations and significant differences in total emissions for the entire domain, as well as individual maximum and average emissions per cell.

These differences were expected and are most likely explained by the use of EDGARv32 emission factors and activity data on national application scales versus the bottom up stack test and fuel balance calculations that are typically part of the development of the NEI. Additionally, as some source categories in the EDGAR 32 Fast Track 2000 (EDGAR 32FT2000) are typically based on national fuel balance calculations, they do not explicitly take into account U.S. local, state, or regional emission reduction programs promulgated since 2000.

Table 3 and Figures 2 through 10 show the quantitative differences (both in emissions and spatial distribution) of the major pollutants (SO₂, NO_x, NMVOC, and CO) identified in this analysis for the NEI2002 and EDGAR 32FT2000. Because the NEI99 and EDGARv32 1990 and 1995 inventories are predecessors to the NEI2002 and EDGAR 32FT2000 emission sets, respectively, the spatial distribution of emissions from these earlier inventories is about the same as their later vintage versions. For this reason, we have chosen to exclude maps of the pre-2000 data at this time.

Table 2. Elevated source categories.

| EDGAR Code | Source Category Name |
|-------------------|--|
| F10 | Fossil Fuel Use - Industry |
| F20 | Fossil Fuel Use - Power Generation |
| F30 | Fossil Fuel Use - Other Transformation Sector |
| F40 | Fossil Fuel Use - Residential, Commercials, and Other Sectors |
| F70 | Fossil Fuel Production and Transmission - Coal Production |
| F80 | Fossil Fuel Production and Transmission - Oil Production, Transmission, and Handling |
| F90 | Fossil Fuel Production and Transmission - Gas Production and Transmission |
| I10 | Industrial Processes - Iron & Steel |
| I20 | Industrial Processes - Non-Ferrous Metal |
| I30 | Industrial Processes - Chemicals |
| I40 | Industrial Processes - Building Materials |
| I50 | Industrial Processes - Pulp & Paper |
| I60 | Industrial Processes - Food |
| I70 | Industrial Processes - Solvent Use/Misc |
| I90 | Industrial Processes - Miscellaneous Industry |
| L41 | Biomass Burning - Deforestation |
| L42 | Biomass Burning - Savanna Burning |
| L43 | Biomass Burning - Agricultural Waste Burning |
| L44 | Biomass Burning - Vegetation Fires |
| L45 | Biomass Burning - Deforestation Post Burn Effects |

As presented in Table 3 and illustrated in Figure 2, EDGAR 32FT2000 anthropogenic emission estimates for SO₂ and NMVOC are approximately thirty percent higher than same source estimates of these pollutants from the NEI 2002. Total NO_x emissions from EDGAR 32FT2000 are slightly lower (four and a half percent) than the NEI total emissions for this pollutant.

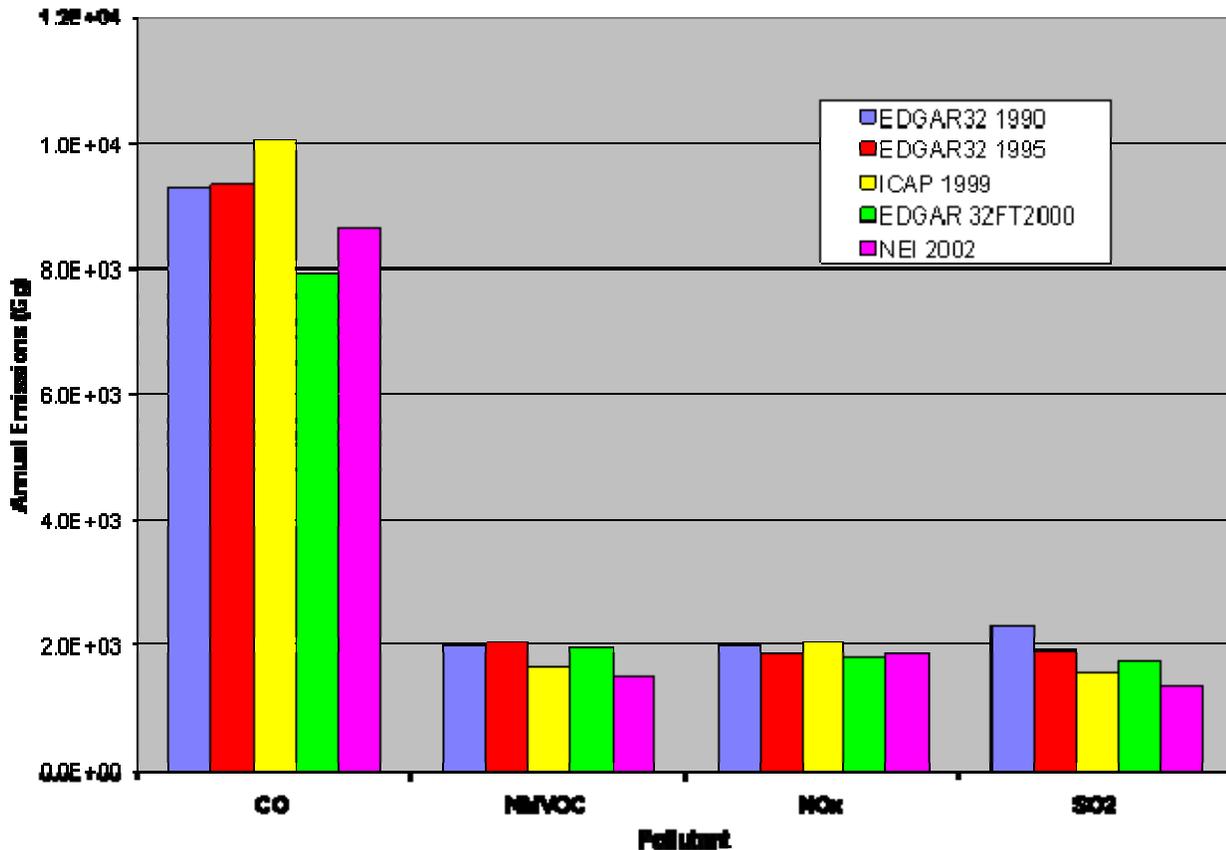
Possibly of greater importance, however, than total emissions in the domain, are the maximum emissions for any one grid cell. These estimates can represent an air cell that is transported during an intercontinental modeling simulation and as shown in Table 3, EDGAR 32FT2000 values can be overestimated by close to four hundred times (NMVOC) compared to NEI 2002 calculations. Similarly, both SO₂ and NO_x are estimated in EDGAR 32FT2000 at fifty and one hundred and eighty times higher, respectively, than bottom up NEI calculations for these same pollutants. These overestimates can lead to invalid estimates of precursor pollutants or resultant chemical contribution to air quality in both local and downwind areas.

Spatially, the distribution of emissions appears to be of good correlation. Typically we find that higher emitting cells are centered on population zones and metropolitan areas. However, it is important to note that these are the same areas that have taken significant steps to implement abatement programs to reduce emissions impacting the well being of their residents. These also are the areas where we would expect to see significant emission differences.

As an example of potential differences in activity and emission rate levels between the two mapped inventories, the purpose of Title IV of EPA's Clean Air Act Amendments is to reduce the

adverse effects of acid deposition through reductions in annual emissions of SO₂ by ten million tons from 1980 emission levels, and to reduce NO_x emissions by approximately two million tons from 1980 emission levels in the forty-eight contiguous States and the District of Columbia.

Figure 2. Anthropogenic emission totals (all sources) for U.S. gridded domain.



These reductions not only have an impact on total emissions within each grid cell, but also have impact on transportable components of these pollutants as the sources controlled by this regulation are those with relatively high emission release points. The majority of these reductions occurred between 1995 and 2000 from coal-fired power plants in the eastern U.S. As can be seen in Figures 3 and 4 and to a lesser extent in Figures 5 and 6, the EDGAR data sets still appear to maintain high emission rates associated with these NO_x and SO₂ emitting sources while the NEI inventory has implemented reductions (and therefore lower emissions) in these same cells.

Similarly, on a more localized scale, southern California has implemented significant ozone precursor reduction strategies through rules controlling VOC emissions from numerous uses of solvents in industrial, commercial, and general purpose cleaning and degreasing activities. The lower left of Figures 7 and 8 identify this difference in actual emission calculations in the NEI versus the extrapolation of data using historical trends statistics.

Table 3. Total anthropogenic emission statistics for national gridded U.S. domain.

| Inventory | Pollutant | Annual Emissions (Gg) | | |
|----------------|-------------------|-----------------------|-----------|-----------|
| | | Total | Maximum | Average |
| EDGAR32 1990 | SO ₂ | 2.346E+03 | 4.690E+01 | 2.867E+00 |
| | NO _x | 1.997E+03 | 8.140E+01 | 2.374E+00 |
| | NM _{VOC} | 1.984E+03 | 1.110E+02 | 2.365E+00 |
| | CO | 9.298E+03 | 5.230E+02 | 1.108E+01 |
| EDGAR32 1995 | SO ₂ | 1.926E+03 | 5.860E+01 | 2.354E+00 |
| | NO _x | 1.899E+03 | 8.450E+01 | 2.258E+00 |
| | NM _{VOC} | 2.038E+03 | 1.180E+02 | 2.429E+00 |
| | CO | 9.349E+03 | 5.460E+02 | 1.114E+01 |
| ICAP 1999 | SO ₂ | 1.585E+03 | 3.985E+01 | 1.854E+00 |
| | NO _x | 2.048E+03 | 3.427E+01 | 2.374E+00 |
| | NM _{VOC} | 1.677E+03 | 2.942E+01 | 1.945E+00 |
| | CO | 1.005E+04 | 1.999E+02 | 1.165E+01 |
| EDGAR 32FT2000 | SO ₂ | 1.757E+03 | 5.170E+01 | 2.047E+00 |
| | NO _x | 1.807E+03 | 8.240E+01 | 2.086E+00 |
| | NM _{VOC} | 1.958E+03 | 1.080E+02 | 2.258E+00 |
| | CO | 7.927E+03 | 4.620E+02 | 9.175E+00 |
| NEI 2002 | SO ₂ | 1.343E+03 | 3.414E+01 | 1.566E+00 |
| | NO _x | 1.892E+03 | 2.954E+01 | 2.185E+00 |
| | NM _{VOC} | 1.501E+03 | 2.174E+01 | 1.732E+00 |
| | CO | 8.657E+03 | 1.291E+02 | 1.002E+01 |

Figure 3. National SO₂ emissions from NEI 2002. All anthropogenic sources (Gg).

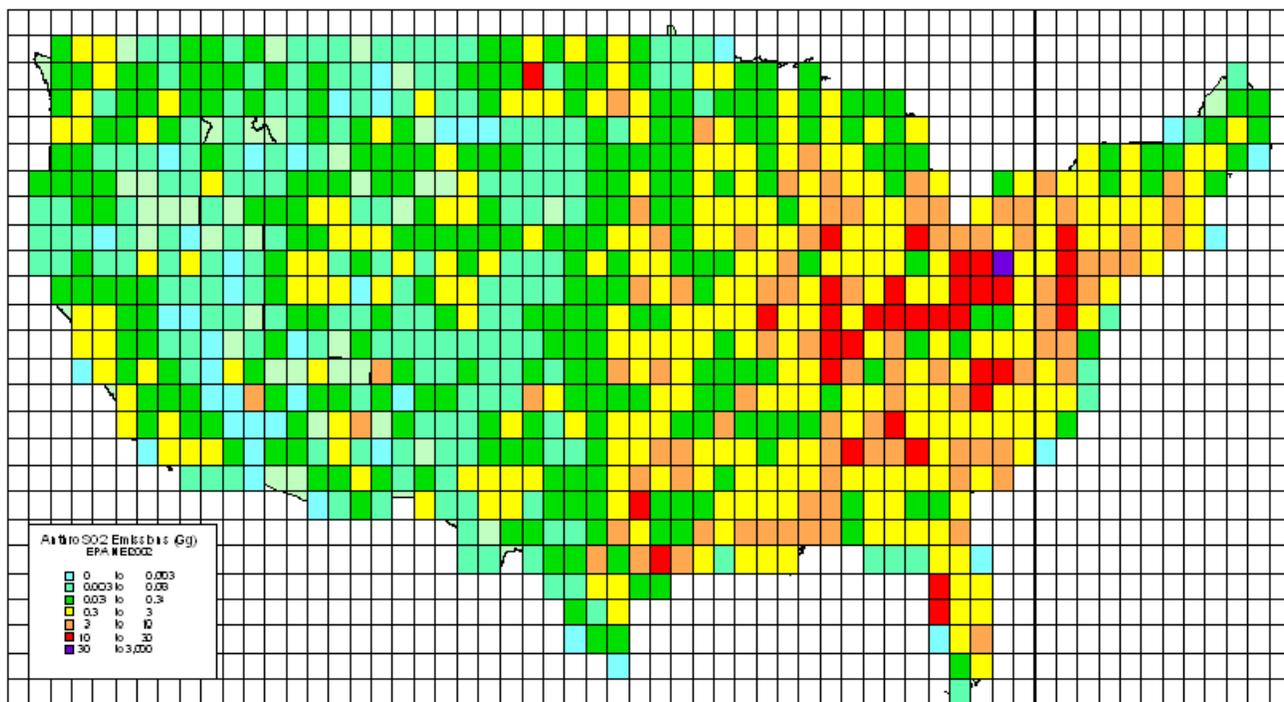


Figure 4. National SO₂ emissions from EDGAR 32 FT 2000. All anthropogenic sources (Gg).

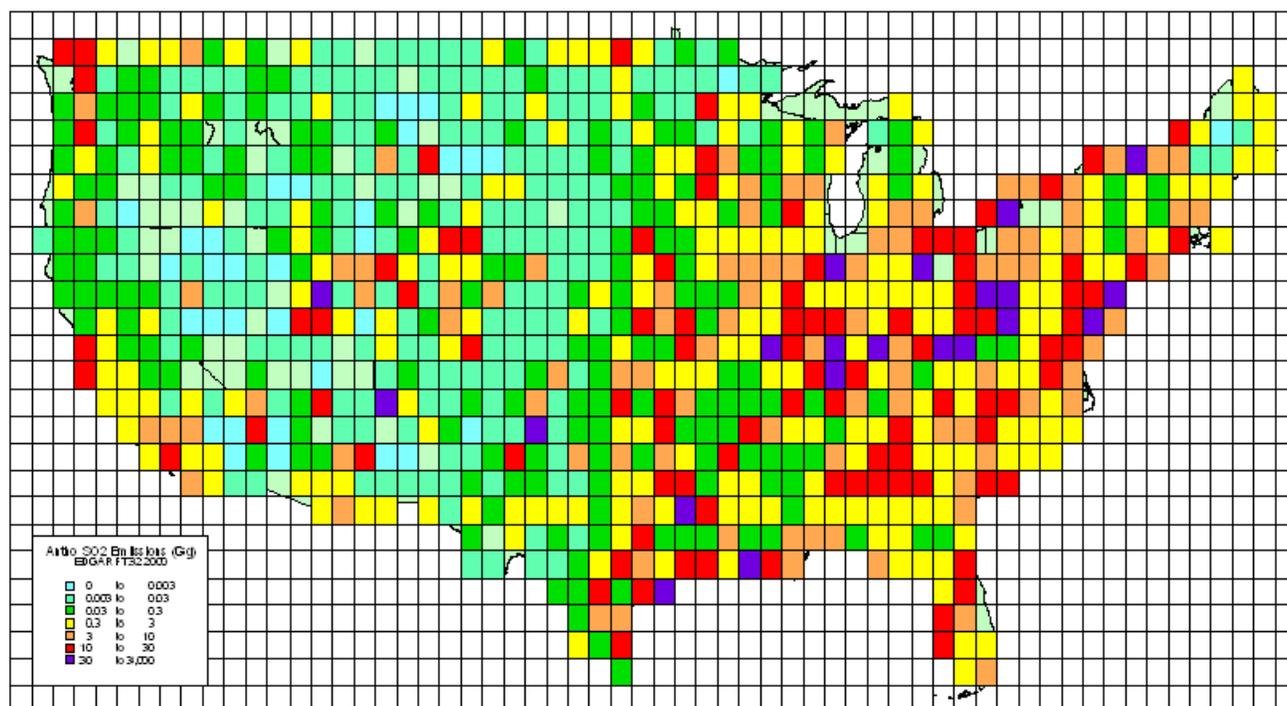


Figure 5. National NO_x emissions from NEI 2002. All anthropogenic sources (Gg).

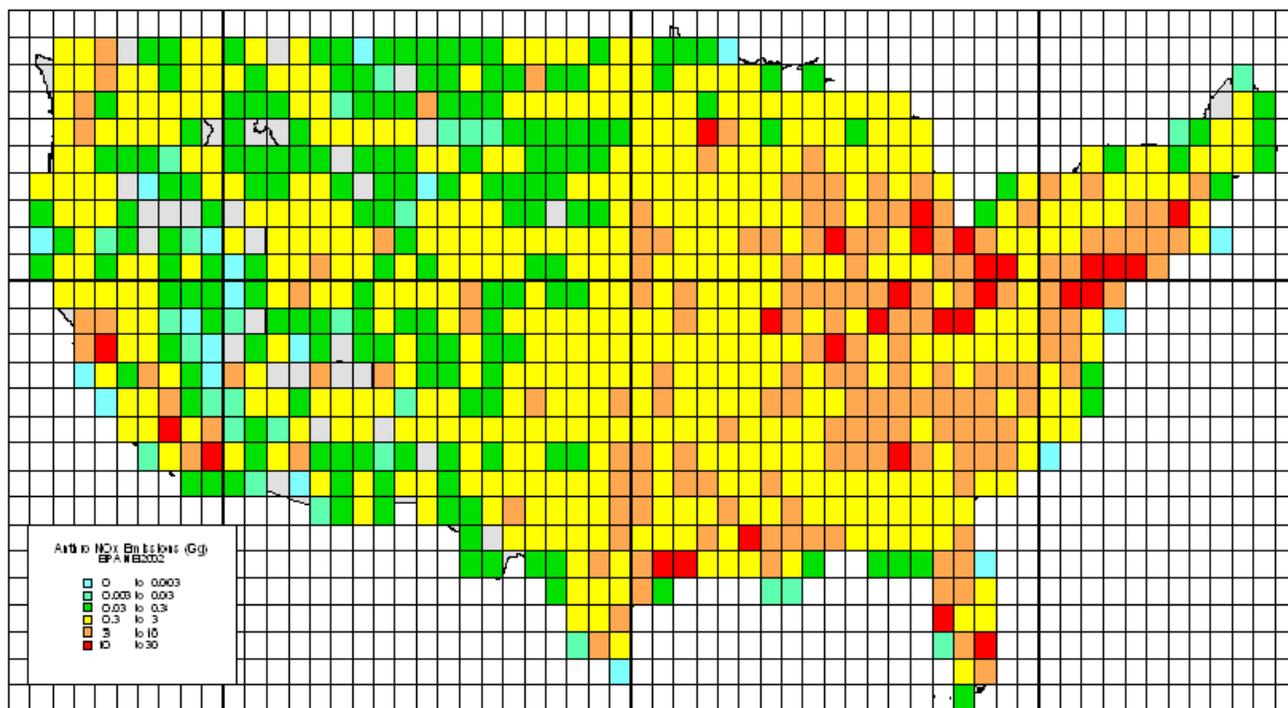


Figure 6. National NO_x emissions from EDGAR 32 FT 2000. All anthropogenic sources (Gg).

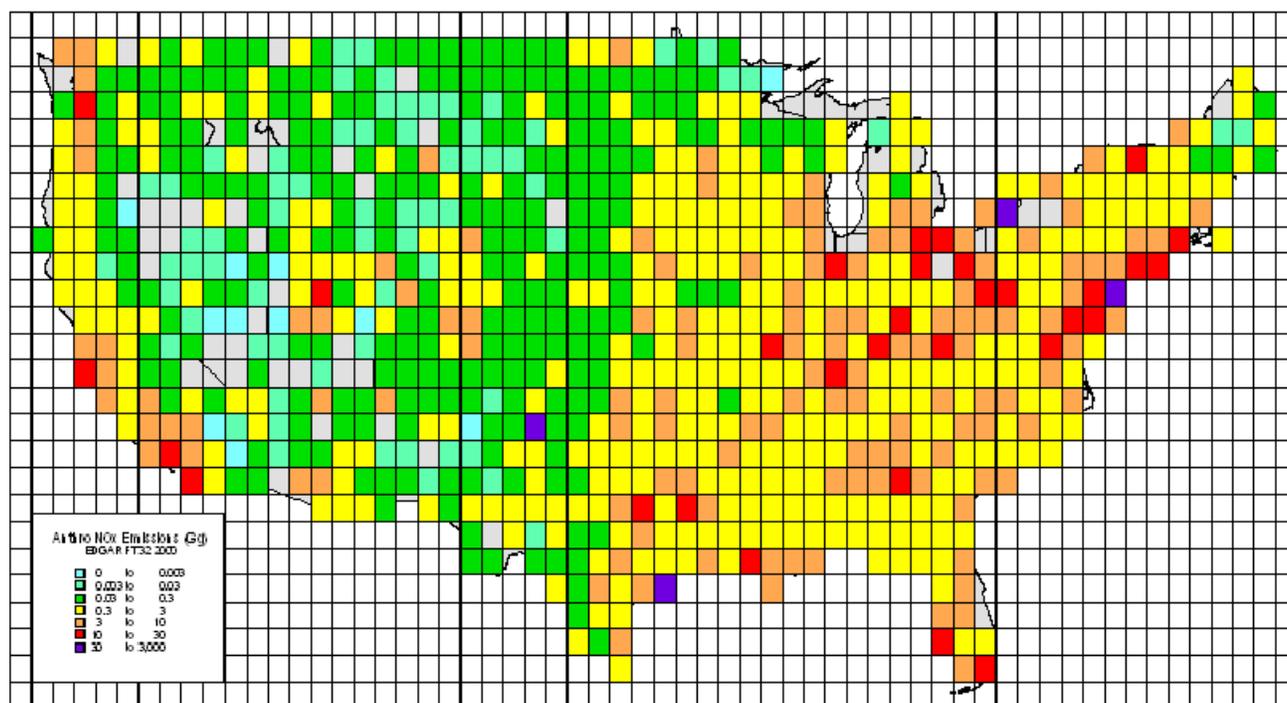


Figure 7. National NMVOC emissions from NEI 2002. All anthropogenic sources (Gg).

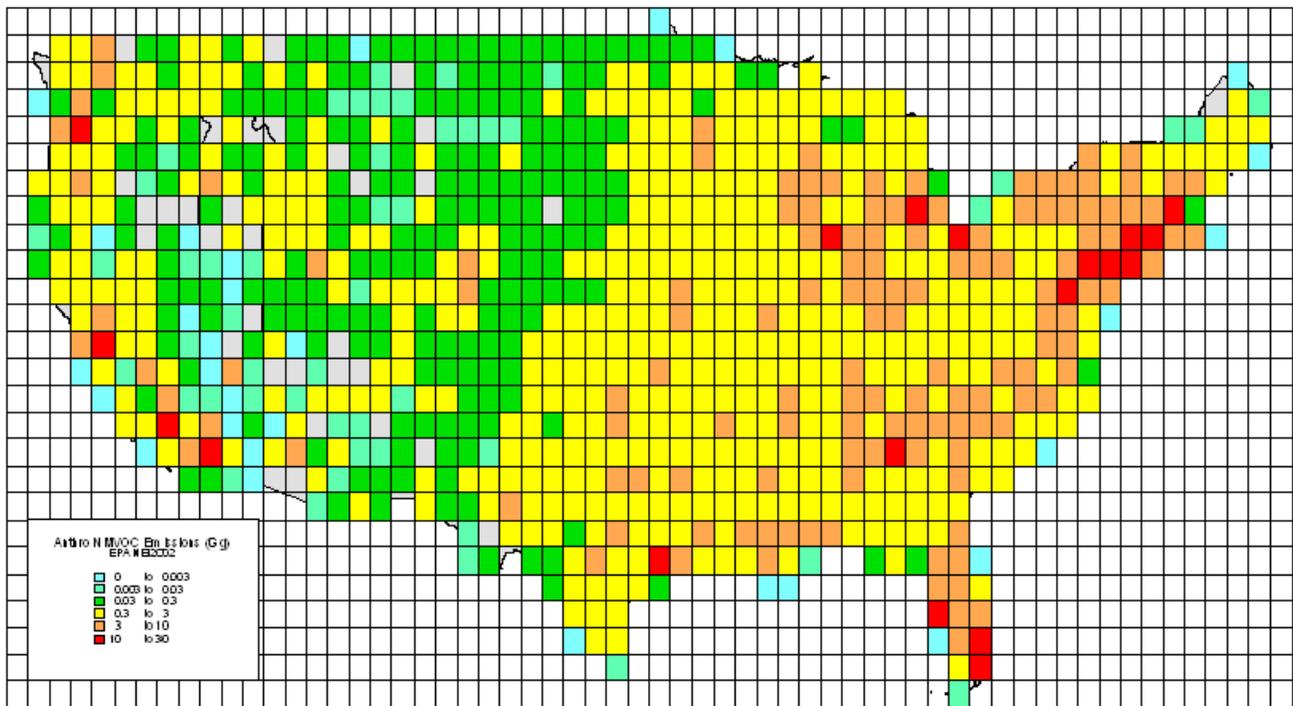


Figure 8. National NMVOC emissions from EDGAR 32 FT 2000. All anthropogenic sources (Gg).

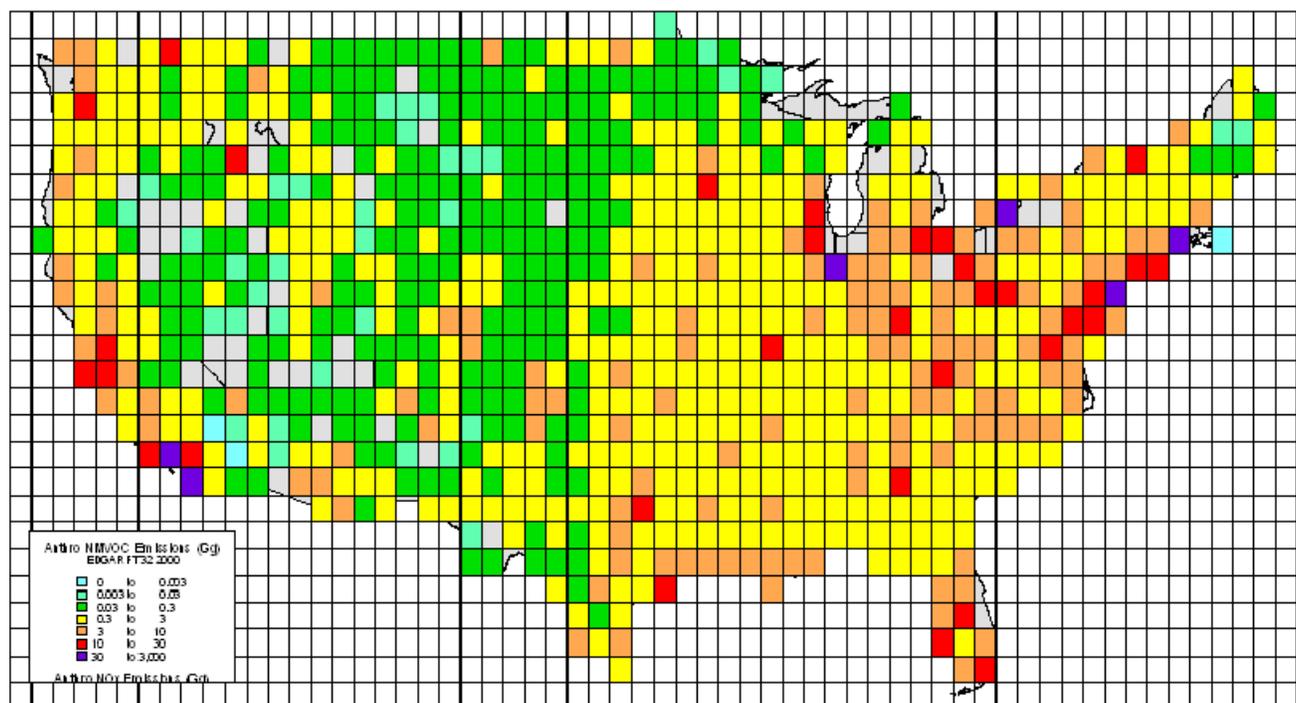


Figure 9. National CO emissions from NEI 2002. All anthropogenic sources (Gg).

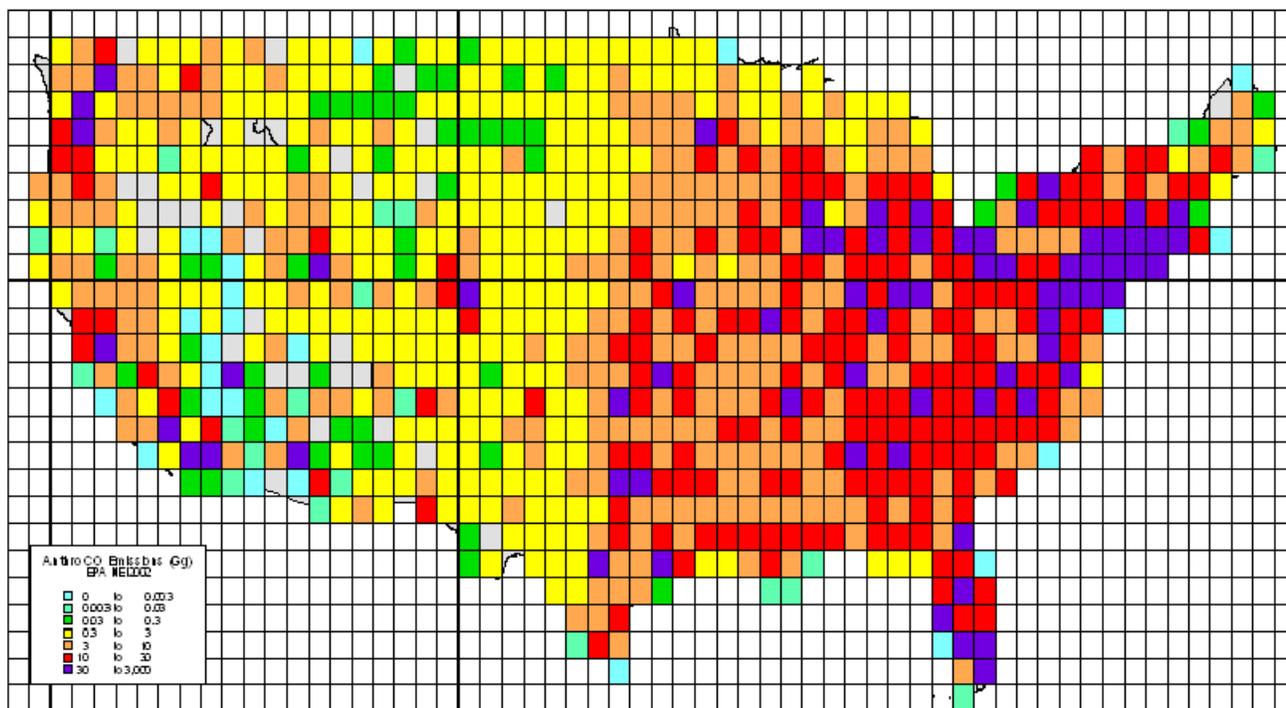
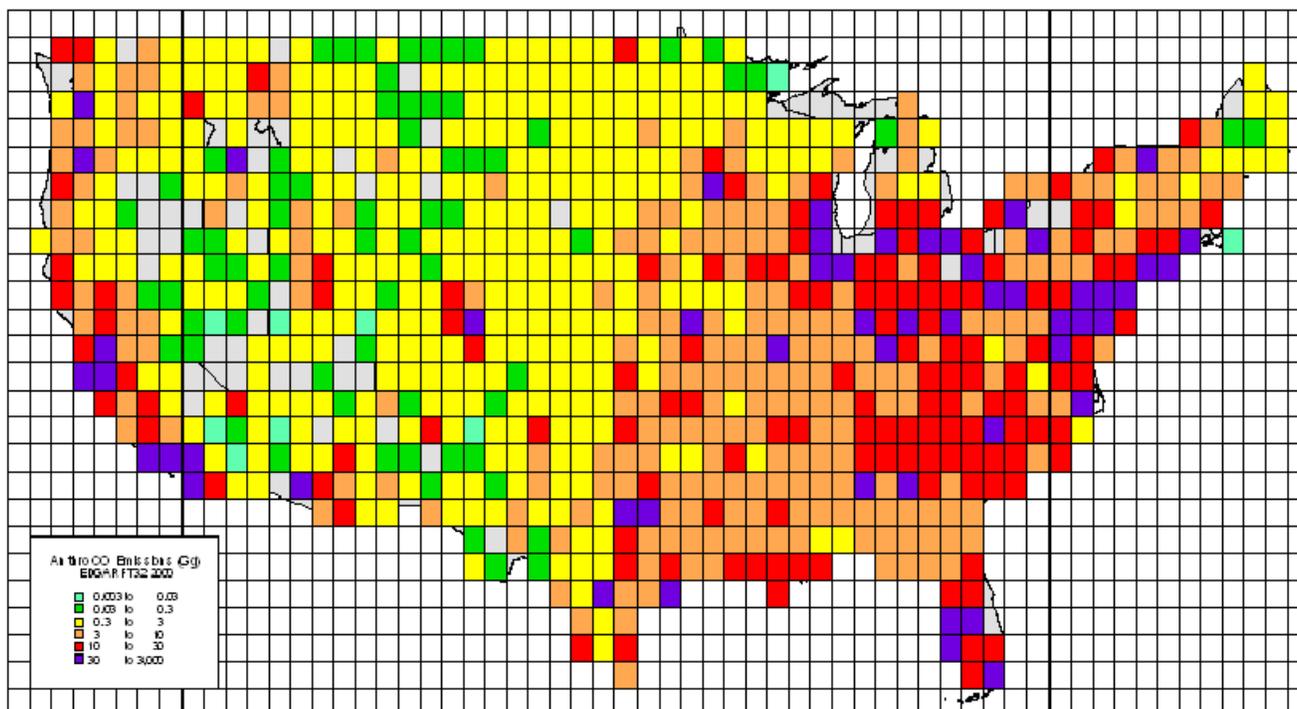


Figure 10. National CO emissions from EDGAR 32 FT 2000. All anthropogenic sources (Gg).



Elevated Source Types

As we review the individual anthropogenic source category types which have the largest emission differences between the NEI and EDGAR inventories, those categories with a strong meteorological correlation and localized control (onroad mobile sources) and those with high transport components (elevated industry and power production) shift to the top of the list. This section focuses exclusively on elevated source categories from the two most current emission inventories used in the global modeling of the United States; the EDGAR 32 Fast Track 2000 and EPA NEI 2002.

Low level sectors, like transportation categories, have a significant impact on ozone and particulate matter concentrations in localized geographic areas. These are not typically the sources which we are concerned about in relation to short-term, long range global transport. It is the categories on our elevated source list and emissions from those source types where our focus centers. Studies have reported that emissions generated at the surface can be transported around the earth in a matter of ten days (EPA, 2004). When these emissions are injected or transported into vertical layers higher than a modeled low level ground layer, they can make their way to other international airsheds in a fraction of that time.

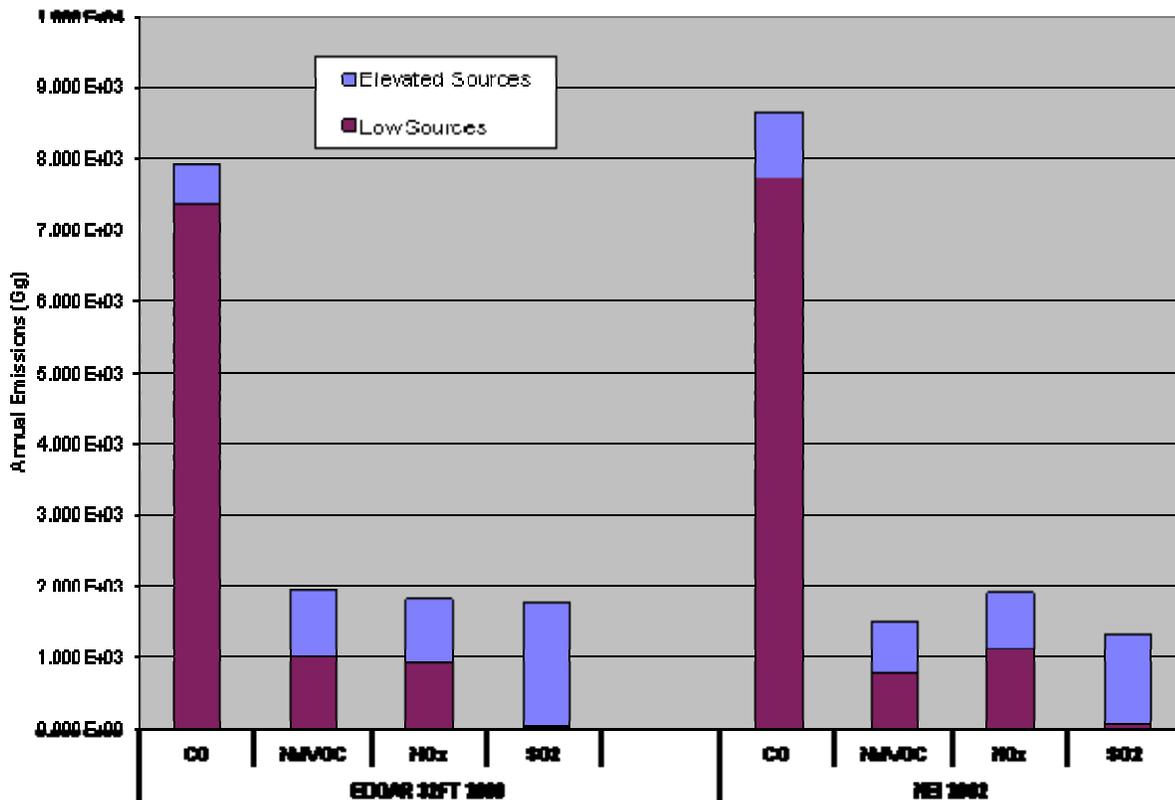
Recent analyses have reported that over 70% of ozone produced in the northeastern United States is transported out of the region (EPA, 2004). This transport has a temporal and spatial influence, so it is essential that emissions from these transport sources, when used in intercontinental modeling efforts, be characterized with the greatest possible certainty in time and space.

As is shown in Figure 11, elevated source emissions are a major component of three of the four analyzed pollutants in this study for our contiguous U.S. domain. NMVOC, NO_x, and SO₂ are associated with source categories that are generally elevated in nature, including power generation, fuel processing, and industrial processes. The fourth pollutant, carbon monoxide, is generally a product of onroad and nonroad mobile source combustion and typically categorized as a low level pollutant.

In 2002, SO₂ emissions from power production facilities contributed to over three quarters of the annual total in many parts of the United States. Combined with non-transport categories, over ninety five percent of SO₂ emissions can be attributed to elevated sources on a national scale. Similarly, close to half of all NO_x and NMVOCs are the result of industry and power production

Table 4 and Figures 12 through 18 show the quantitative differences (both in emissions and spatial distribution) of the major pollutants identified in elevated sources from the NEI2002 and EDGAR 32FT2000. Again, because the NEI99 and EDGARv32 1990 and 1995 inventories are predecessors to the NEI2002 and EDGAR 32FT2000 emission sets, the spatial distribution of emissions from these earlier inventories is about the same as their later vintage versions. For this reason, we have chosen to exclude maps of the pre-2000 data. Additionally, because our focus is on most recent inventories used in global transport modeling, we have also excluded NEI 1999 and EDGARv32 1990 and 1995 emissions from the statistical tables.

Figure 11. Elevated source type contribution to annual emissions for U.S. gridded domain (Gg).



Focusing solely on those emissions from elevated source categories, Table 4 shows that the EDGAR 32FT2000 anthropogenic emission estimates for elevated sources SO₂ and NMVOC have increased to thirty five and thirty two percent higher than same source estimates of these pollutants from the NEI 2002. Instead of seeing a lower level of NO_x emissions from EDGAR 32FT2000 as was estimated in the total anthropogenic source calculations, we now see that the EDGAR 32FT2000 emissions are higher by seventeen percent than comparable sources in the NEI 2002.

Even more significant to long range transport than the increased difference in total elevated source emissions, the maximum emissions difference for any one grid cell from these sources has changed. Where before we saw differences in maximum grid cell emission values of fifty (SO₂), one hundred eighty (NO_x), and close to four hundred times (NMVOC), these difference estimates have shifted to forty four (SO₂), three hundred and thirty five (NO_x), and three hundred and sixty (NMVOC) percent higher in EDGAR 32FT2000 emissions compared to NEI 2002 calculations.

Again, spatially, the distribution of emissions again appears to be of good correlation. Typically we find that higher emitting cells are distributed consistently between the two data sets but note that the order of magnitude within each cell can be of significant difference.

Table 4. Elevated source anthropogenic emission statistics for national gridded U.S. domain.

| Inventory | Pollutant | Annual Emissions (Gg) | | |
|----------------|-------------------|-----------------------|-----------|-----------|
| | | Total | Maximum | Average |
| EDGAR 32FT2000 | SO ₂ | 1.728E+03 | 4.841E+01 | 2.131E+00 |
| | NO _x | 8.896E+02 | 4.717E+01 | 1.097E+00 |
| | NM _{VOC} | 9.345E+02 | 5.246E+01 | 1.155E+00 |
| | CO | 5.508E+02 | 3.594E+01 | 6.808E-01 |
| NEI 2002 | SO ₂ | 1.274E+03 | 3.364E+01 | 1.484E+00 |
| | NO _x | 7.608E+02 | 1.084E+01 | 8.786E-01 |
| | NM _{VOC} | 7.062E+02 | 1.142E+01 | 8.154E-01 |
| | CO | 9.270E+02 | 2.599E+01 | 1.073E+00 |

Figure 12. Elevated source type comparison of annual emissions for U.S. gridded domain (Gg).

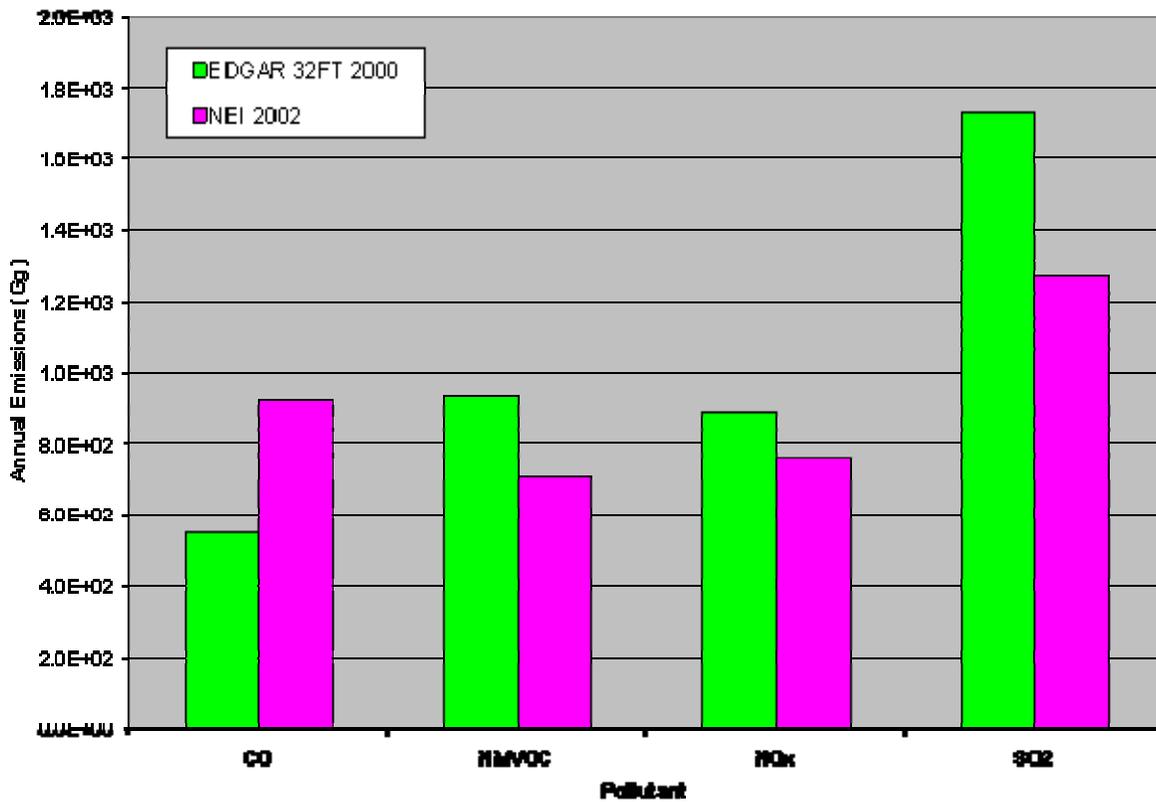


Figure 13. National SO₂ emissions from NEI 2002. Elevated anthropogenic sources (Gg).

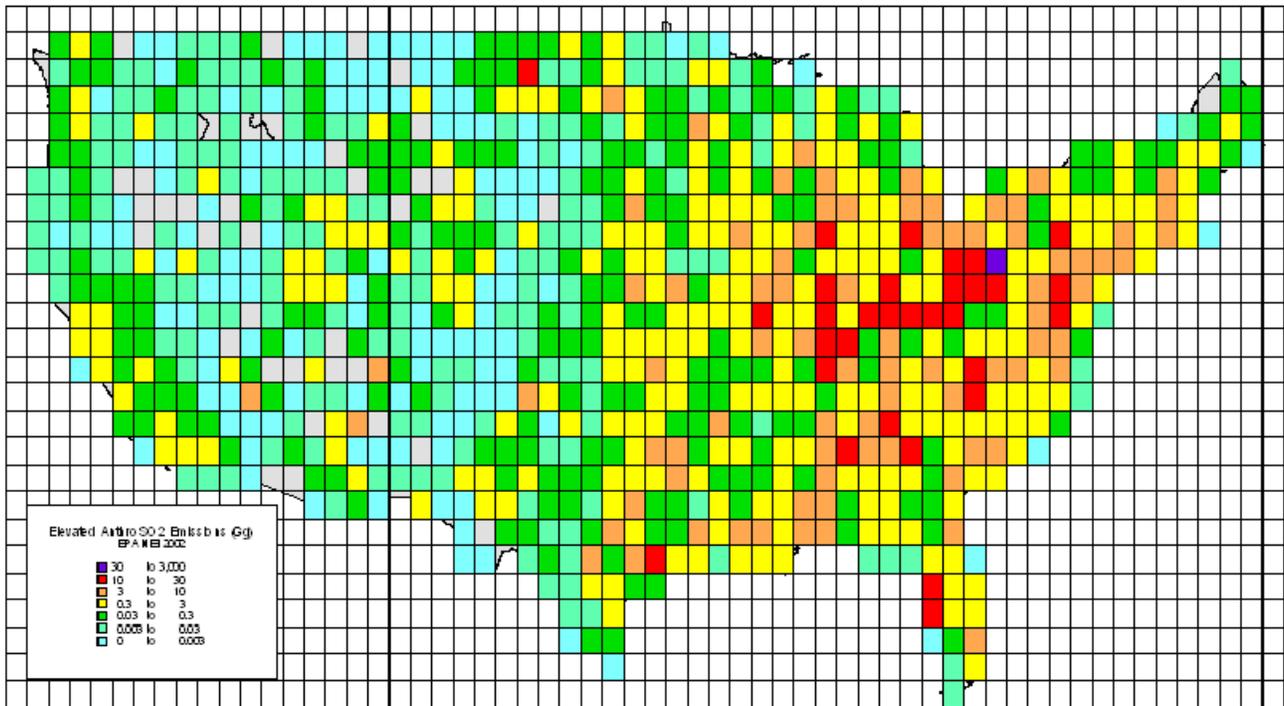


Figure 14. National SO₂ emissions from EDGAR 32 FT 2000. Elevated anthropogenic sources (Gg).

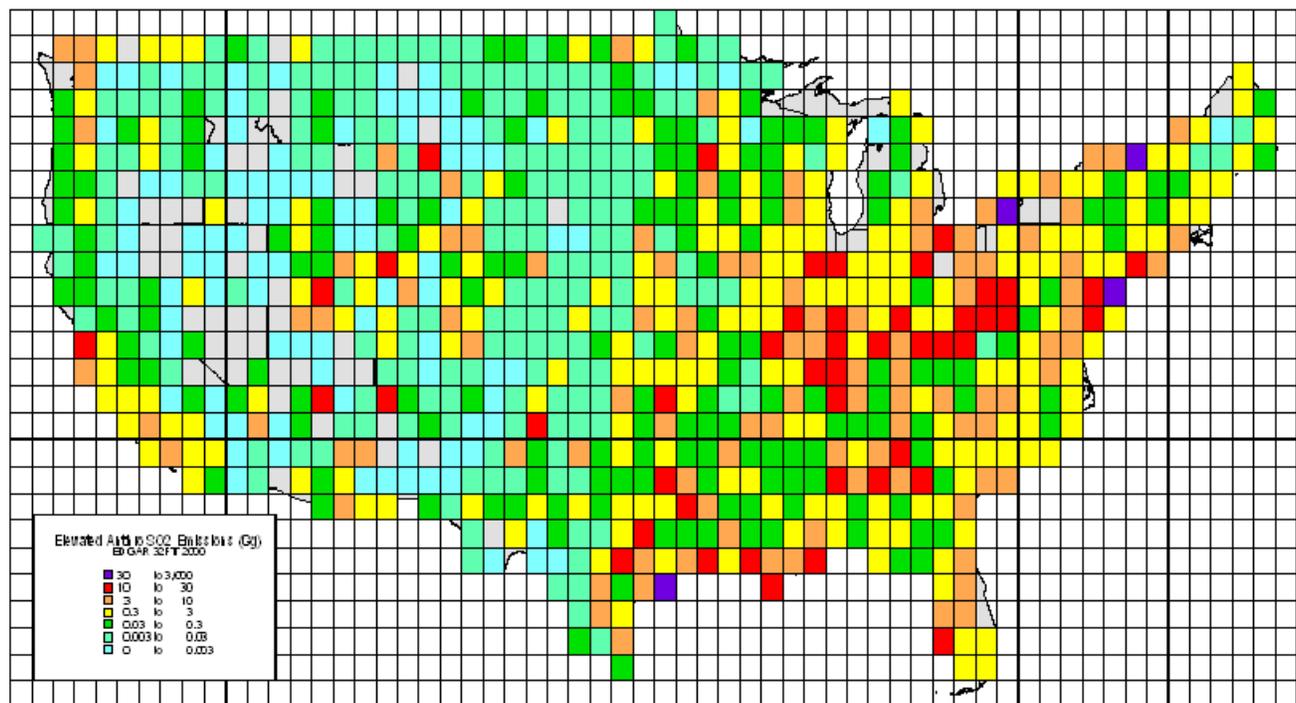


Figure 15. National NO_x emissions from NEI 2002. Elevated anthropogenic sources (Gg).

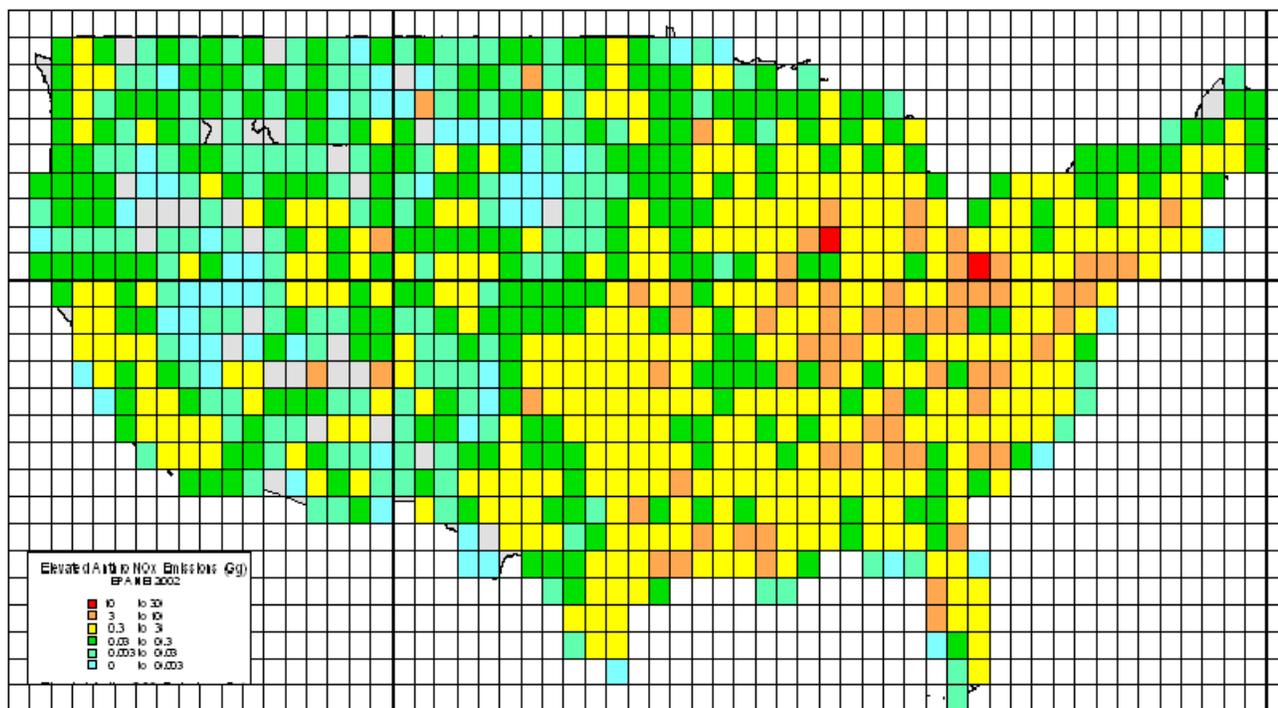


Figure 16. National NO_x emissions from EDGAR 32 FT 2000. Elevated anthropogenic sources (Gg).

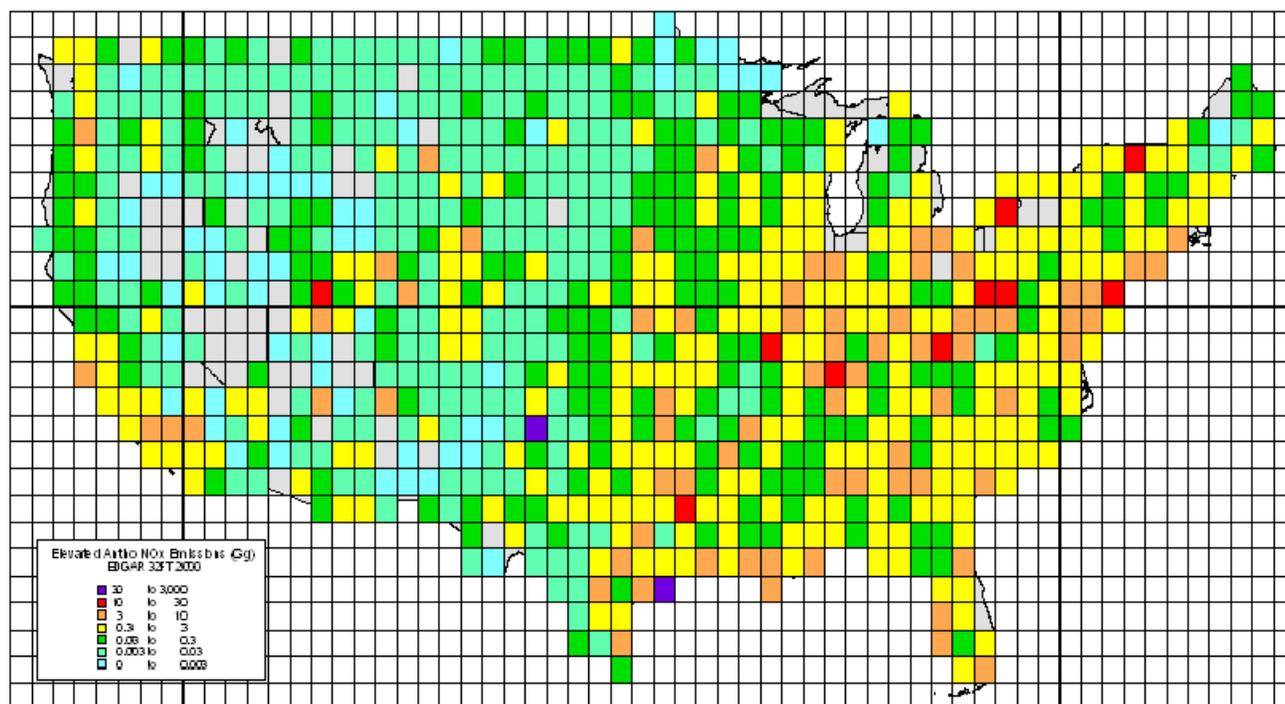


Figure 17. National NMVOC emissions from NEI 2002. Elevated anthropogenic sources (Gg).

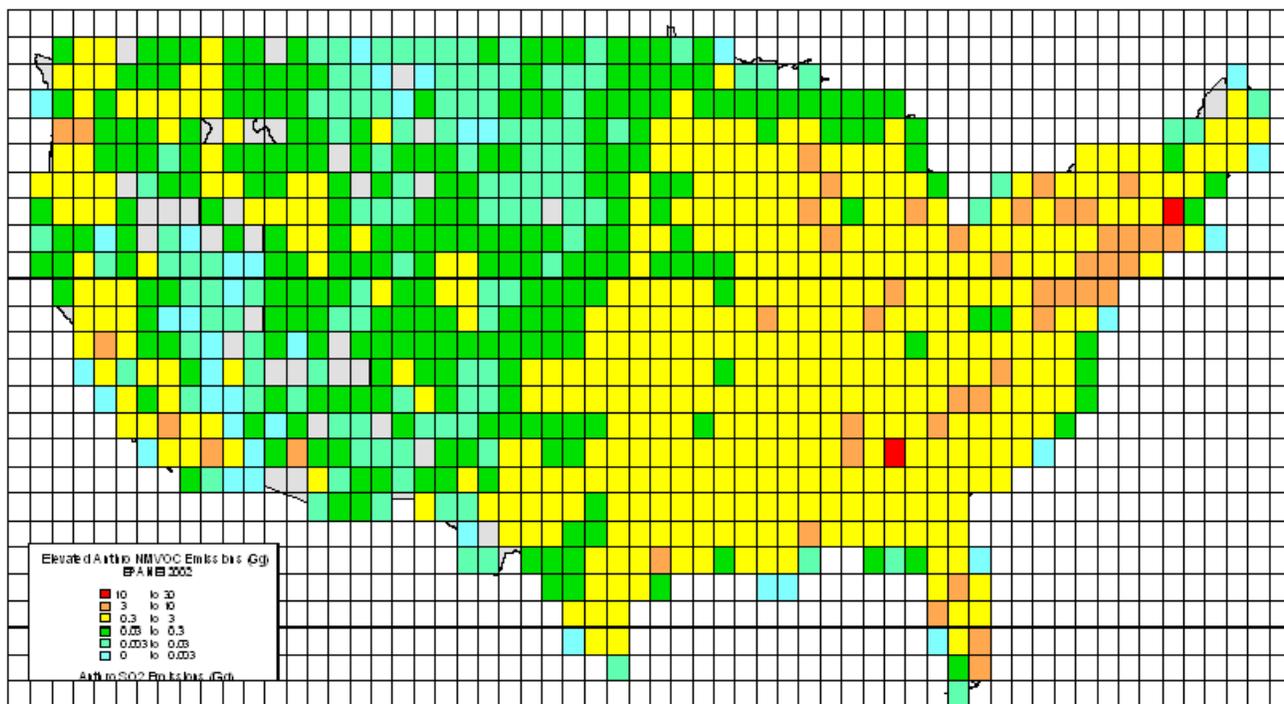
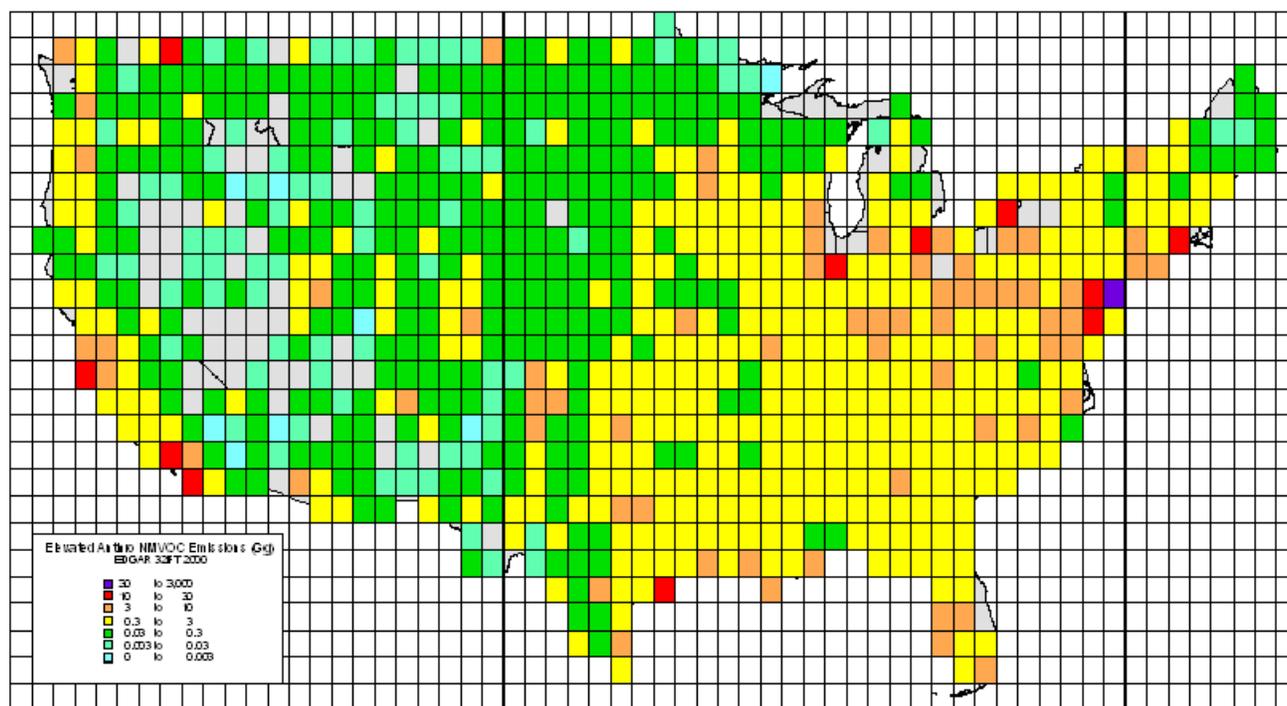


Figure 18. National NMVOC emissions from EDGAR 32 FT 2000. Elevated anthropogenic sources (Gg).



CONCLUSIONS

Today's global inventories track and maintain emissions for thousands of different categories for numerous air pollutants over multiple temporal and geographic scales. Once used for local-scale impacts and tracking, these data sets have become necessary for policy makers and researchers alike to simulate transport of air pollutant emissions on regional, national, and global levels. To make matters more complicated, the preparation of these inventories is oftentimes unique to individual areas and even inconsistent within regional and international airsheds.

With the participation of multiple countries in international collaborations and resolutions, emission inventories have recently been reviewed and prepared with increased scientific scrutiny. This adjustment of purpose has created the need for these data to be made even more complete, accurate, timely, transparent, and affordable to science bodies in need of their use.

Our objective as scientists working to attend to these collaborations is to compare emission estimates contained among various regional and international inventories and to reconcile differences based on the alternate methods of emission inventory preparation.

Inventory Comparisons

Through a series of statistical and graphical representations of the various inventories used in the modeling of U.S.-generated emissions and their contribution to global transport, we have identified notable differences in the estimates of annual emissions among these data. These differences were anticipated and in fact allow the reader to better understand the relationship between regional and global data preparation and processing.

While the regional and global scale inventories reviewed in this analysis showed good correlation among the spatial distribution of total anthropogenic emissions and elevated source types, regional and national gradations of emissions as a result of applied abatement programs is still not replicated accurately. In the U.S., this holds especially true for those source types with elevated release points that have a greater contribution to the short-term transported component of inter-continental air quality degradation.

Globally consistent methods and factors and historical trend forecasting of emission inventories are useful tools in areas where the national tracking of pollutants has not fully evolved. However, as culpability of contribution to global air quality is further analyzed and enhanced relationships among international airsheds become clear, there is an increased burden on minimizing uncertainty placed on the scientific community establishing the associations. For this reason, the benefits of integrated emission inventories and their availability and ease of distribution become apparent.

Benefits of Integrated Inventories

The importance of a common integrated emission inventory derived through international coordination invites a uniform reporting structure, consistency among reporting entities, the ease of information submission and modification, and reduction of burden for information exchange.

Our long term goal as inventory data developers and users should be the advancement of an emissions inventory that is universally available to all who want to access its information, is of high-resolution and source and facility specific, is comprehensive with respect to pollutants and sources, is

well documented and easily duplicated, and is based on comparable methodologies and factors. This inventory would allow for ease of technical and policy evaluations by data providers, stakeholders, and other interested parties.

Many nations currently have operable inventory management systems designed to receive, store, process, display and output emissions data. These systems are also being modified to receive, store, process, and display combinations of the activity data and emissions calculation methods used to estimate emissions inventories. Continued work is underway to provide inventory display capabilities which will include GIS functionality, tabular and flat file data formats, graphs and charts, and the ability to capture these displays in user-defined report formats.

Until this goal comes to fruition, however, the representativeness of global and national emission inventories for purposes of long range transport in hemispheric transport modeling will remain uncertain and speculative. For this reason, analyses like the one conducted here contribute to an improved understanding the differences one may see in using emissions data from differing sources.

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KEY WORDS

Emission Inventories

International

Comparison

EDGAR

NEI

Transport