Advancing Climate and Air Quality Database Management Systems and Emissions Inventories in Developing Countries

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ABSTRACT

Effective climate and air quality management require knowledge of the sources of air pollutants in a region, the ability to understand and project the emissions from those sources, and the ability to handle the regulatory processes associated with controlling emissions from those sources. This is an ongoing challenge for regions with ample resources; the challenge is even greater for developing counties with limited information and disparate local planning programs. Over the last decade, ISSRC has supported these countries to advance a scientific-based air quality management process that will allow for the consideration and mitigation of regional and global air pollution impacts. A cornerstone in this effort has been the creation of a tool and methodology for developing and projecting emissions from the mobile source sector. The IVE model and data collection process has been applied now in over 19 countries.

Recently, ISSRC has expanded its focus to create an Integrated Environmental Database system (IED) to manage all air quality and energy related information. The system has the ability to create and project present and future emission, fuel and energy inventories for area and point sources for local, long-range, and climate-change pollutants including analysis of source control impacts and control cost. It has been designed to integrate policy analysis for urban air, water, solid waste, and climate change pollution. The internet-based system is especially designed to work and adapt to a variety of regions and data availability. The IED is currently being applied in four cities across Latin America and Asia.

INTRODUCTION

Air quality management is a complex issue. Unlike many other government functions, like taxation or infrastructure development, there is no historic government analog available to implement the air quality improvement programs, and management of air quality requires interaction between many different government sectors (such as transportation, energy, water resources, urban planning). Furthermore, the science of air pollution formation is complex and sometimes has counterintuitive explanations, and new confounding issues seem to crop up regularly. The US experience provides a useful example of the myriad of issues that can impede air quality progress. Air quality standards were first set in place in 1970 with the first attainment deadline of 1975. This law had all of the necessary elements to ensure success, including standards, deadlines, and enforcement elements with consequences for failing to attain. However, actual air quality progress was slower than originally expected in many regions, and many areas still do not meet attainment levels set decades ago. Why has the US struggled in tackling air pollution? There have, of course, been some economic considerations as well as political elements. However, some of the reasons can be linked to the shortcomings of the emissions inventory and management system itself. Early systems focused on single pollutants, sometimes even the wrong pollutant, which led to poor planning and prediction tools. The system also led to overlooking key emissions sources and accounting for cultural trends. As we have learned about the complexity of pollutant formation, health impacts, and interactions, our planning tools and predictive abilities have improved. Our computational abilities have allowed us to now model very detailed systems almost in real-time, and look into the future with more accuracy than ever. Many of these tools are available for developing countries as well, as they are beginning their efforts at developing an air quality management system. Organizations in most developing countries have at some level an air monitoring network, and the governments and universities throughout the world have the ability to run complex photochemical and meteorological modeling for prediction of air quality levels. Still, there are some of the same fundamental shortcomings of these developing and existing programs that still impede our ability to put together a scientifically sound air quality management plan.

For example, Chongqing, Guadalajara, Sao Paulo, and Shanghai, where ISSRC has worked, have primarily point source inventories with little ability to understand overall sources of pollution or predict future trends. They have no way to update or improve their pollution related information, and when a new pollutant of consequence enters the picture, a whole separate inventory or plan is set up without adequate integration. With key elements missing, they often turn to US-based emissions factors and models to 'fill-in' the gaps of their inventory. While often adequate as a first–look analysis, the US surrogates are too narrow in their design and become liabilities when trying to develop a comprehensive plan for the individual region.

One of ISSRC's goals is to help developing countries to overcome these shortcomings and build an effective air quality management process that achieves real air quality improvements that are sustainable into the future. Our initial approach has been to focus in three areas:

1) Provide a free tool to estimate on-road mobile source emissions in developing countries
2) Make available free information designed to help developing countries implement their air quality management policies
3) Create a free database system to manage complex environmental related data to allow for effective and meaningful air quality improvement plan development

This paper will outline the progress to date in these areas. Before continuing, we would like to acknowledge our partners and funders in these efforts, including the Hewlett Foundation, Energy Foundation, World Bank, EMBARQ, USEPA, and countless universities and agencies around the world.

BODY

The International Emissions Model (IVE) and Its Application

The International Emissions Model is an on-road mobile source model developed for use in any region to predict criteria, toxic, and global warming pollutants. It can be compared with the MOVES or EMFAC models in terms of the types of vehicles and level of detail that it accounts for, and has been rated the most easy to use and most accurate model for developing countries in an independent journal review (Yu, 2009). The IVE model was initially developed using a grant from the USEPA in 2000. Since then, various improvements have been incorporated into consecutive model updates, the latest one being version 2.0.2 updated in March of 2010. A detailed description of the IVE model development and structure can be found in other conference proceedings and papers and so the reader is encouraged to view these for more information (Davis, 2006; Davis, 2005; Liu, 2010; Lents 2009).

Along with the model itself, ISSRC has developed a suite of data collection tools and methodology for collecting pertinent information to be used in the IVE (or any) mobile source model. The data collection and training has been carried out in various field programs beginning in 2000 in Mexico City, Mexico, and Santiago, Chile, and has since been implemented with local agencies in 19 locations. (Figure 1).

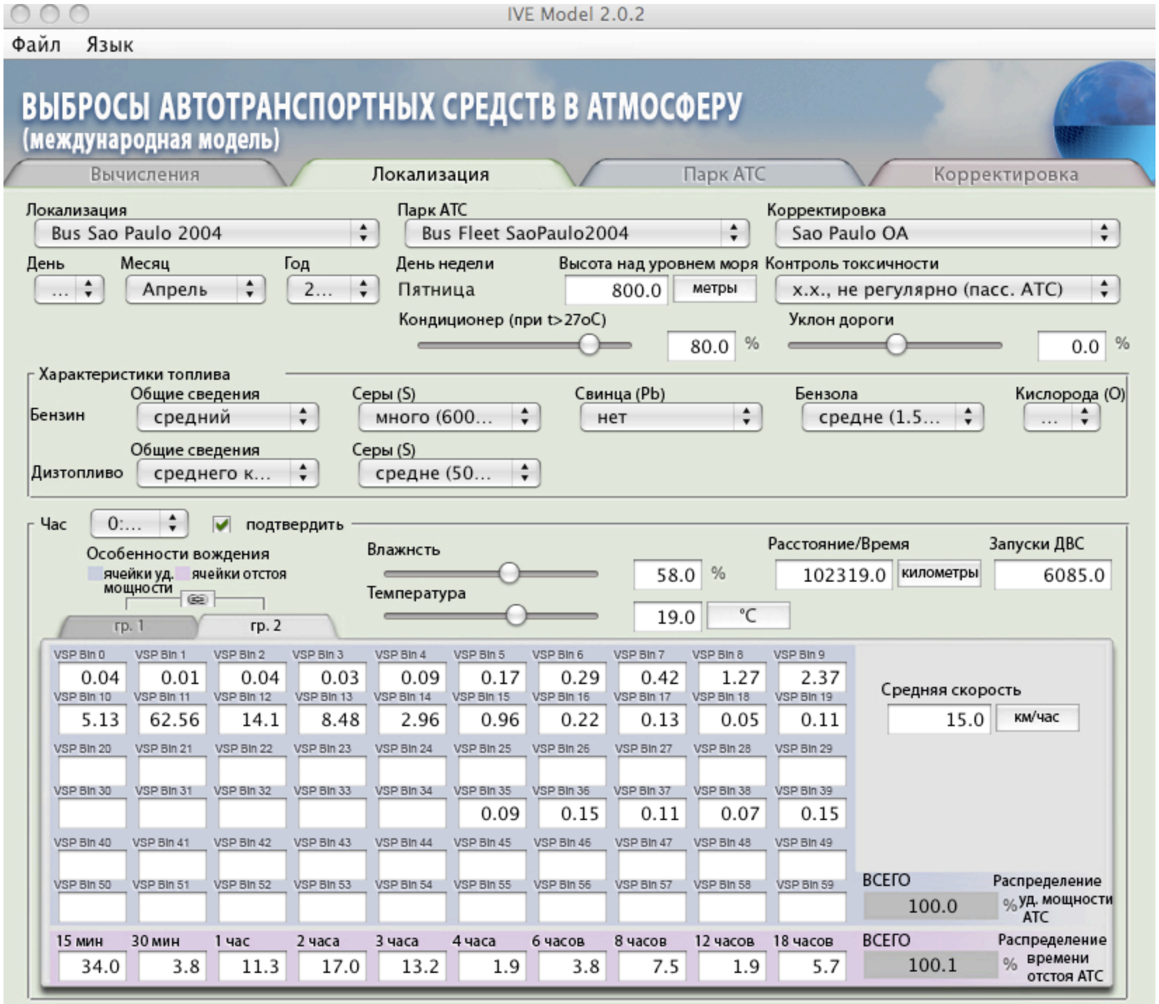
Figure 1. Map of IVE field studies and model implementation.

The data collection includes the following elements:

1) Fleet Information: a procedure for collecting information on the quantity and type of vehicles in operation on the road in a city.
2) Emissions Information: on-road data collection process using PEMS systems
3) Activity Information: on-road data collection process and tools to capture the amounts, temporal and velocity pattern of driving and starts of various vehicle categories. The IVE model can incorporate information from thousands of hours of collected second by second driving data using a vehicle specific power (VSP) binning approach similar to the approach in the MOVES model.

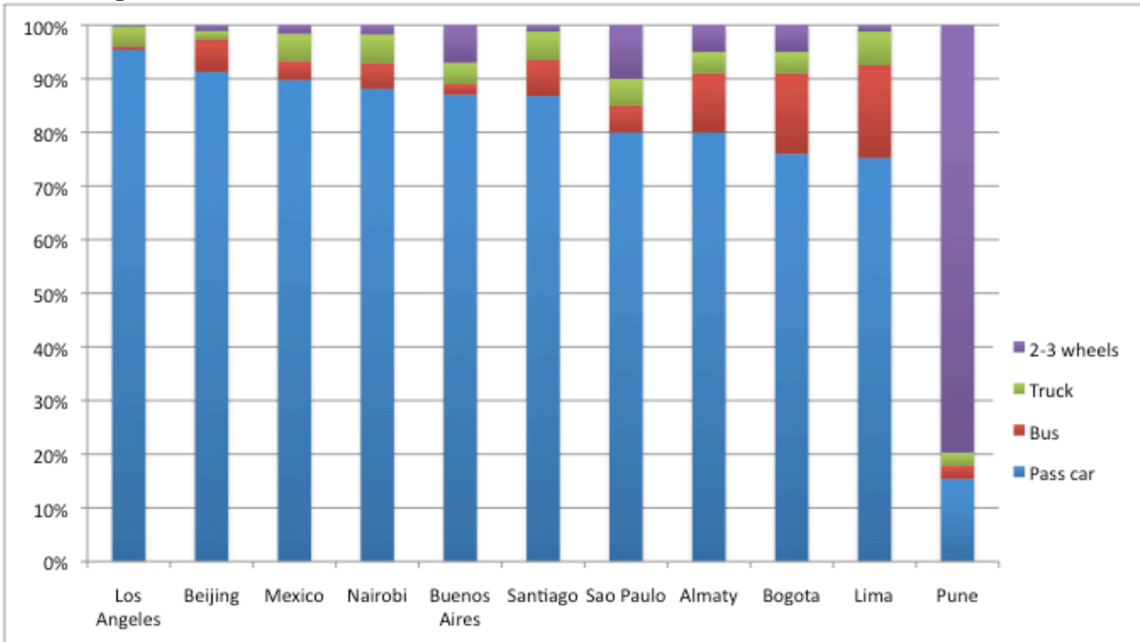
Recent improvements to the IVE model include adding a Russian language option to the already existing English, French, Spanish and Chinese options (Figure 2), updating emission factors from the newest on-road emissions testing by the USEPA and others, and adding a multitude of local fleet and emissions input data.

Figure 2. IVE Russian User Interface



The use of the IVE with the supporting data from the field studies have allowed for some interesting comparisons of the mobile source sectors from different regions. ISSRC now has a comprehensive database of the types, driving styles and emissions from various urban areas around the world, available at www.issrc.org/ive. Figure 3 gives an example of some of this information, and more information can be found in the literature and at www.issrc.org/ive (Osses, 2004; Lents 2005; Liu, 2007, Barth, 2007). All this information is collected and can be used as input files into the IVE model, where ultimately, the information is used to predict current (and future) emissions profiles.

Figure 3. Example of Variation between Cities Collected in Field Studies



The Air Quality Management Book

The Handbook of Air Quality Management is a Hewlett-funded effort to get important air quality management information onto the web for use by developing countries (Lents, 2009). This effort is currently underway. The idea for the handbook is to provide a resource for developing countries to be used in designing an effective air quality management program that will have all the necessary elements for success. The book is designed to be updatable from anywhere in the world by persons with approved names and passwords. An online version of the book in its present form can be accessed at www.aqbook.org. Present authors of the book include James Lents, Michael Walsh, Kebin He, Nicole Davis, Mauricio Osses, Sebastian Tolvett, and Huan Liu, and is partially translated into Spanish and Chinese. While only part of the resource is completed at this time, the website receives more than 500 hits per month with no advertising. Additional authors that have expertise in needed subject areas are being recruited to assist in the completion of the book. In the long term, it is planned for experts around the word to keep the web site up to date for use by all persons involved in air quality management processes.

When completed, the Handbook will cover the following topics in great detail:

- Introduction: Human Development and Air Quality
- Air Quality and Health and Welfare
- Developing a Framework for Effective Air Quality Management
- Identifying Air Quality Problems
- Identifying Sources of Air Quality Problems
- Estimating Emissions from Sources of Air Pollution
- Development of an Emissions Inventory
- Air Quality Modeling
- Developing Emission Reduction Strategies
- Implementation of Air Quality Management Programs
- Fuels and Energy
- Life-Cycle Analysis and Its Application to Air Quality Improvement
- Building Capacity, Involving Stakeholders, and Reaching the Public
- Policy Development and Organization

The Integrated Environmental Database (IED) and Its Application

Overview

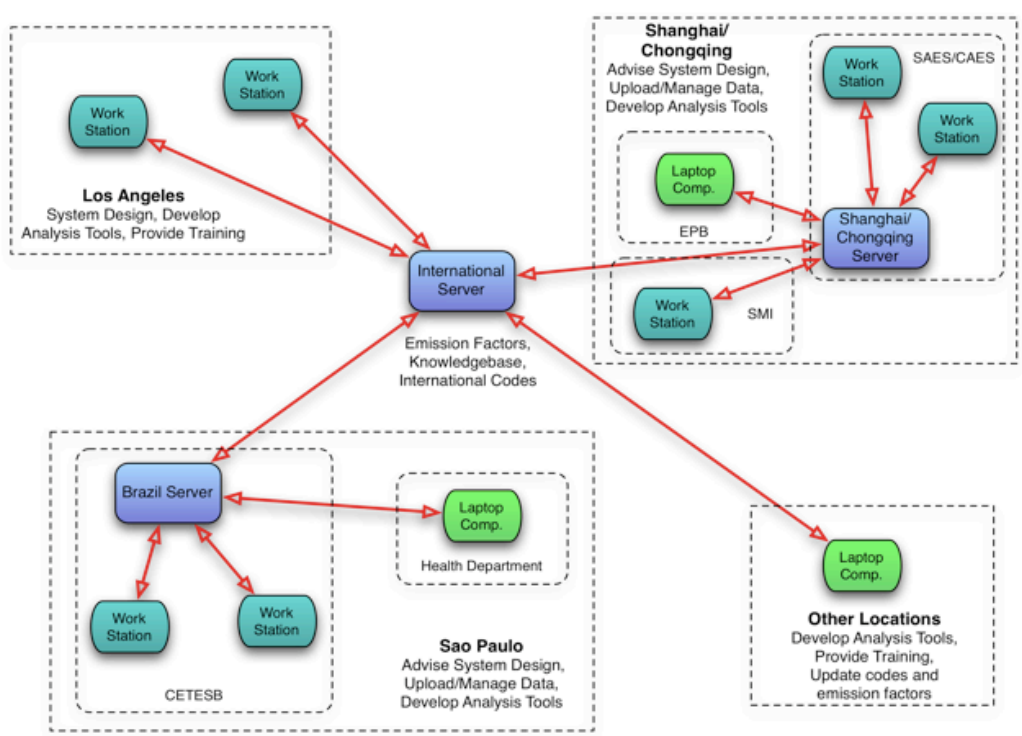
The Integrated Environmental Database is ISSRC's most recent endeavor. The IED is quite simply a flexible framework designed to manage the tracking and prediction of energy and air quality related information. Its key purpose is to calculate and project air quality emissions, energy requirements, and fuel use for urban regions. Specific information can be attached to each material or pollutant to keep track of ancillary information about the material, including among other things its source, cost, magnitude, timing, growth, and ownership information. The framework itself has been developed with the needs of the current emissions inventory process in mind, as well as the capability of encompassing new materials (ie. pollutants) and sources as science and policy evolve.

The framework was developed with several key requirements:

- The ability to integrate policy analysis for urban air, water, solid waste, and climate change pollution
- Support prediction and emissions inventory for regional and local scales
- Support policy programs such as emission cap and trade and credit trading programs
- Provide multiple levels of data security
- Allow remote access & upload of information
- Provide the system free of charge

The ability to integrate the system with various departments within the government and allow remote access for developers as well as individual companies or contractors that are responsible for entering in information necessitates online access to the framework. Therefore, the framework was developed to be an SQL database with a main international server and interaction with local servers. (Figure 4).

Figure 4. Organizational Structure of the IED



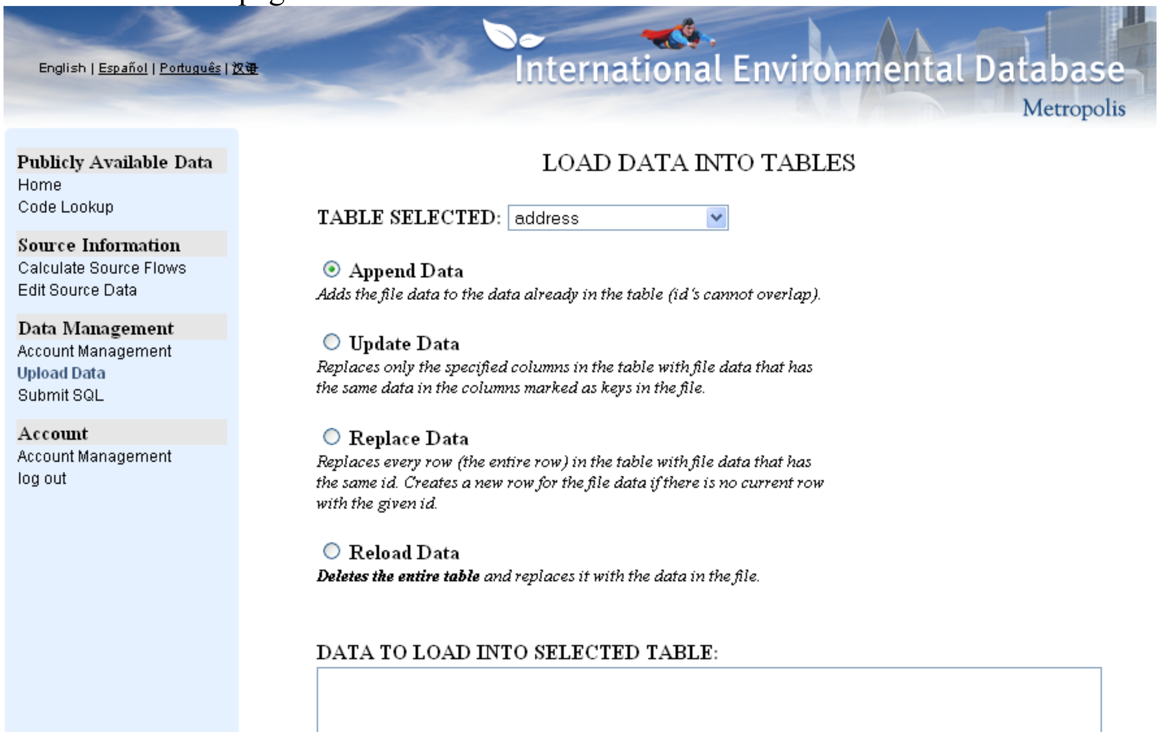
<u>Accessing and Entering Information Into IED</u>

Interaction with IED can be done directly with the server or through a web interface (Figure 5). Several levels of security are included to allow different users access to different sections of the database (for example, a person working in area sources is only allowed to modify area sources, or a company owner is only allowed to upload information for his company) or different levels of access to the database (for example, a planner may be allowed read-only information, and the developer is allowed to modify information).

Figure 5. The IED Web-Interface front page

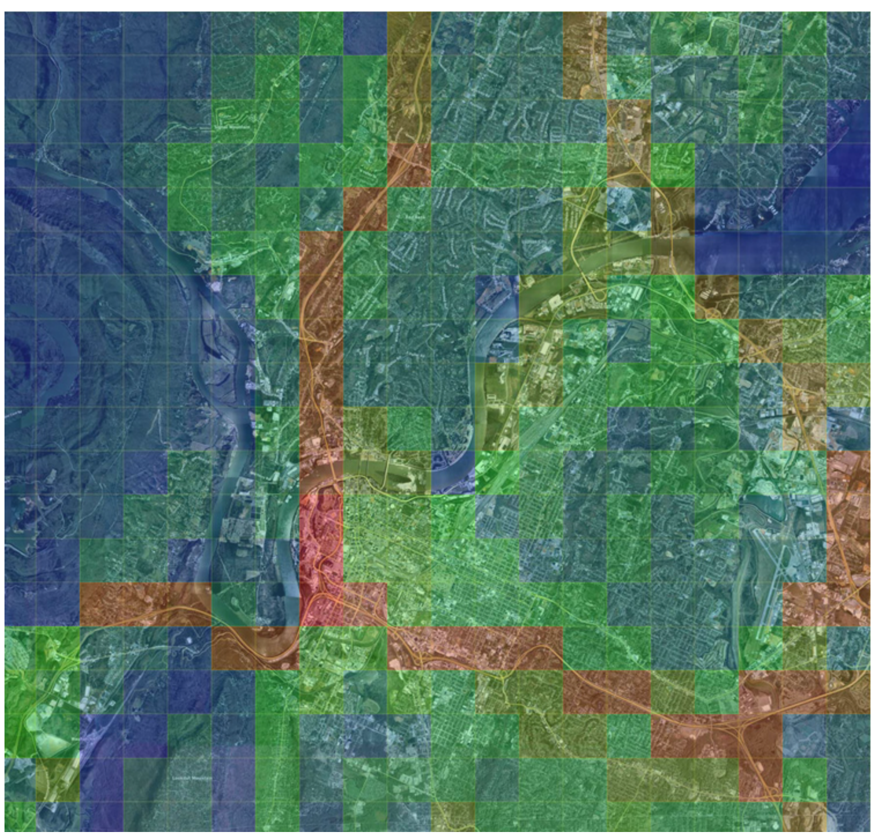
Once in the database, the user will be able to select various menu options. The various option screens allows for looking up emission factors, calculating emissions from a set of criteria, or inputting new information. The inputting of new information is allowed in several ways: the user can copy a selection from excel and paste it directly in the web interface using, or upload it directly to the database in the server (Figure 6). Similarly, any query result can be copied into excel directly, or saved as a file on the system.

Figure 6. Data Load Webpage in IED



Various tools are being developed for assisting entries into the database. For example, there is a program that assists in assigning population, temperature, or other spatial variables via Google map images for an area. (Figure 7).

Figure 7. Screenshot of a Map overlay to assist in Inputting Data or viewing results



Creating Emissions Inventories

Once the information is input into the database system, the user can develop countless inventories for various purposes. Three broad uses of this system are described below.

1)Inventories to Support Modeling

The database has been developed to support inventories that are spatially and temporally resolved. Every pollutant has either a specific latitude/longitude (and for point sources, release height) associated with it, or is assigned a file that has the spatial distribution by grid cell. A certain distribution file can be associated with each source, for example, residential water heaters may be distributed by a map of housing units, residential land use area distribution, or population distribution. Similarly, the temporal distribution may be a function of ambient temperature, or simply input a different constant for each hour of the day. The resolution of the data export is dependent upon the user selection and is limited only by the level of input resolution.

2) Inventories to Support Planning

Once the database has been adequately populated, it has been designed specifically to support planning analysis, to answer questions such as:

- How would implementing a rapid transit system affect fuel usage, criteria, toxic, and global warming emissions?
- What are the top polluting IPCC categories in an area during a specific season?
- What are the differences in emissions and energy use from moving toward a natural gas fleet versus and electric fleet?

3)Inventories to Support Enforcement

The database can also be used to assist on tracking enforcement activities and answering questions such as:

- What is ABC Company's emissions, and last year's emissions and efficiency levels?
- Is Company ABC exceeding its emission cap?
- What quality and certainty is associated with the emission factor for Source X?

An example of how the inventory is output from IED is shown in Figure 8. The emissions, energy use, or any other material may be aggregated at any level to form a resulting inventory for any of the above purposes. This example shows the data result of a specific query - the total VOC emissions from passenger vehicles for the noon hour in the city of Metropolis, under an assumed electric vehicle penetration scenario. The VOC is reported in kg per grid cell, and the total number of processes, or vehicle types, is 24.

Figure 8. Example of Emissions Output for the IED system, for 1 hour at each grid cell

Source Name: All Sources
Region: Metropolitan Region of Metropolis
Class: On-Road Mobile: Passenger Vehicle
Scenario: All Passenger Vehicles Electric Beginning 2015
Flow Material: Volatile Organic Compounds (VOC)
Calculation Time: 2012 - January through March/Weekday - 12:00
Number of Processes: 24
Total Emissions in Region: 1,592 kilogram

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
19	0.644	0.627	0.644	0.644	1.373	2.060	2.746	4.119	0.644	8.966	2.053	2.737	2.737	8.966	2.676	4.013	4.013	2.676	4.106	2.053
18	0.644	0.627	0.644	0.644	1.373	2.746	4.214	1.931	4.013	8.966	2.676	2.676	2.676	8.763	4.013	2.676	2.676	4.013	2.737	2.053
17	1.287	1.254	0.644	1.373	2.060	4.214	4.119	1.881	4.106	8.763	2.676	2.676	2.676	2.676	8.763	2.676	2.676	4.106	2.053	0.620
16	0.620	1.241	1.241	2.060	4.214	2.810	1.931	4.106	4.483	9.859	4.013	4.013	4.013	4.682	8.763	6.020	2.007	2.053	1.338	0.0
15	0.644	0.644	0.620	1.241	4.119	2.746	4.106	2.737	9.859	4.013	2.676	2.676	2.676	7.668	2.676	8.763	1.338	1.338	0.620	0.620
14	0.637	0.637	0.637	1.241	1.985	4.013	4.106	9.859	4.013	2.676	2.676	2.676	2.676	7.587	7.668	8.763	0.620	0.620	1.324	1.338
13	0.620	0.620	1.274	1.274	1.241	1.338	4.013	9.859	4.013	2.676	2.676	1.338	7.668	7.668	4.382	5.351	8.763	2.676	2.676	4.682
12	0.620	0.620	1.274	1.274	1.241	1.241	2.676	9.859	2.676	2.676	2.676	2.191	7.668	4.382	2.676	4.682	4.682	8.763	7.668	4.382
11	0.620	0.620	1.274	1.241	1.324	1.241	2.676	9.859	2.676	2.676	2.676	7.668	7.668	4.382	4.682	4.682	4.013	2.676	8.763	7.668
10	1.254	1.254	1.287	1.254	1.338	1.338	4.013	9.859	7.668	4.382	2.676	7.668	4.382	4.382	2.007	2.676	4.013	2.676	8.763	2.007
9	1.287	1.287	1.254	0.627	2.737	2.007	3.286	10.06	7.828	7.668	1.338	5.351	4.106	2.737	2.737	4.106	4.013	4.013	4.013	9.859
8	1.287	1.287	1.254	2.676	2.737	2.007	3.286	11.20	6.709	6.709	5.463	2.676	4.013	2.676	4.013	2.676	4.013	2.676	2.676	9.859
7	1.287	0.644	2.737	2.737	1.338	2.007	2.007	11.20	6.709	6.709	4.780	4.682	2.676	2.676	4.013	2.676	2.676	2.676	2.676	9.859
6	0.627	0.627	10.09	10.09	9.859	3.286	2.007	11.20	10.06	6.709	4.473	4.382	4.682	4.682	2.676	2.676	2.676	2.676	9.859	9.859
5	4.382	6.020	2.737	2.508	1.287	9.859	9.859	6.573	6.573	9.859	10.06	9.859	9.859	4.382	4.682	2.676	2.676	4.682	7.668	2.676
4	6.020	4.382	2.676	1.254	0.644	1.373	4.682	6.573	3.286	6.573	4.382	7.668	7.668	9.859	9.859	7.668	4.682	9.859	9.859	9.243
3	6.020	4.382	0.620	0.620	2.717	1.324	4.682	2.676	2.007	2.676	4.382	4.382	7.668	7.668	4.382	9.859	9.859	9.859	2.007	2.508
2	2.676	7.668	0.620	2.717	2.717	1.324	4.682	2.676	4.013	4.013	4.382	3.286	4.382	4.382	7.668	7.668	7.668	9.859	4.682	2.508
1	4.682	1.881	0.620	2.717	2.717	1.324	4.682	2.007	4.013	2.676	7.668	4.382	4.382	4.382	6.573	4.382	4.483	4.106	8.763	1.881
0	1.239	0.627	2.574	2.746	2.746	1.324	2.007	2.007	2.007	2.676	4.382	7.668	4.382	4.382	6.573	3.286	3.286	2.007	8.763	1.881

Show Map

show notes/errors - ☑
color table - ☑
hold high/low coloring values - ☐

<u>Implementation Status</u>
As of September 2010, the basic system has been created and populated with both generic and some local emission factor information. Improvements and added features, tools and emissions factors are ongoing to improve this free, open source IED software.

To date, there have been implementation agreements in Mexico City, Guadalajara and Chongqing, and discussions are on-going with Sao Paulo, Santiago, Shanghai to get agreements. A training session will be held in November 2010 where members of planning agencies from South America and Asia will be trained in use of the database and how to effectively populate it as well as the overall air quality management process.

CONCLUSIONS

Many developing countries around the world have established air quality management agencies and developed modeling capabilities, yet are lacking some of the fundamental data and system flexibility for integrating these plans in other areas, such as energy security and climate change programs, as well as effectively comparing control options. ISSRC has focused on several projects to help fill these gaps. The development of the IVE model for enhancing the accuracy and forecasting ability of the mobile source sector has been successfully implemented in well over a dozen areas and has proven to be accurate and easy to use when compared with other models of its type. ISSRC's newest effort to develop an integrated environmental database to track and forecast energy and air pollutant is well underway in several countries. ISSRC will continue to work with these countries with its pilot program and provide training and tools for its ultimate implementation.

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