Developing Emissions for Multi-pollutant Air Quality Modeling in the Middle East

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ABSTRACT

Preparing emissions for modeling local and regional air quality in parts of the world where local inventory data are sparse is a challenge. Results from air quality modeling at regional grid scale resolutions are optimized using country-level emission inventories at a minimum. Alternatively, pre-gridded inventories for regional applications are required at resolutions commensurate with the air quality modeling grid. Spatial, temporal, and chemical data describing the local emission sources are also required to characterize the local air quality problems. This paper presents a case study of building a multi-pollutant emission database for the Middle East. The issues addressed include the development and preparation of the list of inventories for capturing the range of emissions sectors in the region, preparing spatial, temporal, and chemical information for representing the local emission patterns, and methods to evaluate the air quality-model ready emissions for a part of the world where comparable data are sparse. Particular challenges in this work included developing accurate emissions for a modeling domain that covers over 50 countries on three continents, integrating spotty localized inventories with global emissions datasets, and evaluating the accuracy of the model-ready emissions. This paper presents an emissions modeling framework for conducting multi-pollutant air quality modeling with CMAQ. The framework includes SMOKE version 2.4 with a set of utilities for converting pre-gridded inventories of natural and anthropogenic emissions into vertically-resolved emissions for simulating ozone, $PM_{2.5}$, SOA, air toxics, mercury, sea salt, and wind-blown dust.

INTRODUCTION

Global scale atmospheric modeling research has shown that the Middle East is a significant source region for photochemical air pollution (Lelieveld et al, 2008; Li et al, 2001). Reviews of satellite data products identify the Middle East as a region of considerable dust storm activity as well (Washington et al, 2003; Prospero et al, 2002). Despite a unique combination of large anthropogenic emissions sources, related to rapidly growing urban populations (UCB, 2009) and concentrated industrial sites, and topography that is conducive to frequent dust emissions events, there have been relatively few regional-scale modeling studies to assess air pollution exposure in the Middle East (Ajjaji, R et al, 2008; Wheeler and Reid, 2006).

This paper describes the compilation and preparation of emissions data for regional and national scale air quality modeling to assess ambient air pollutant exposures in the United Arab Emirates (UAE). Figure 1 shows the air quality modeling grids selected for a Summer 2007 and Winter 2008 modeling study of UAE air quality. A combination of local, regional, and global scale emissions inventories, local and global geographic information system (GIS) data, and ancillary emission information associated with the United States National Emissions Inventory (NEI) and the European Monitoring and Evaluation Program (EMEP) were used to prepare hourly emissions for conducting multi-pollutant air quality

modeling with version 4.7 of the Community Multiscale Air Quality (CMAQ) modeling system (Byun and Ching, 1999; Byun and Schere, 2006). The multi-pollutant configuration of CMAQ used for this study includes ozone, primary and secondary particulate matter (PM), secondary organic aerosols (SOA), mercury, chlorine, sea salt, and tracers for selected air toxics species. The sources of the emissions input data, how these data were prepared for processing with version 2.4 of the Sparse Matrix Operator Kernel Emissions (SMOKE) system (IE, 2008a), and preliminary validation of the emissions results are presented in this paper. Preliminary results and analysis of gridded and national emissions summaries of a May 2007 emission simulation are provided along with a discussion of how these results can be refined in future emissions simulations.

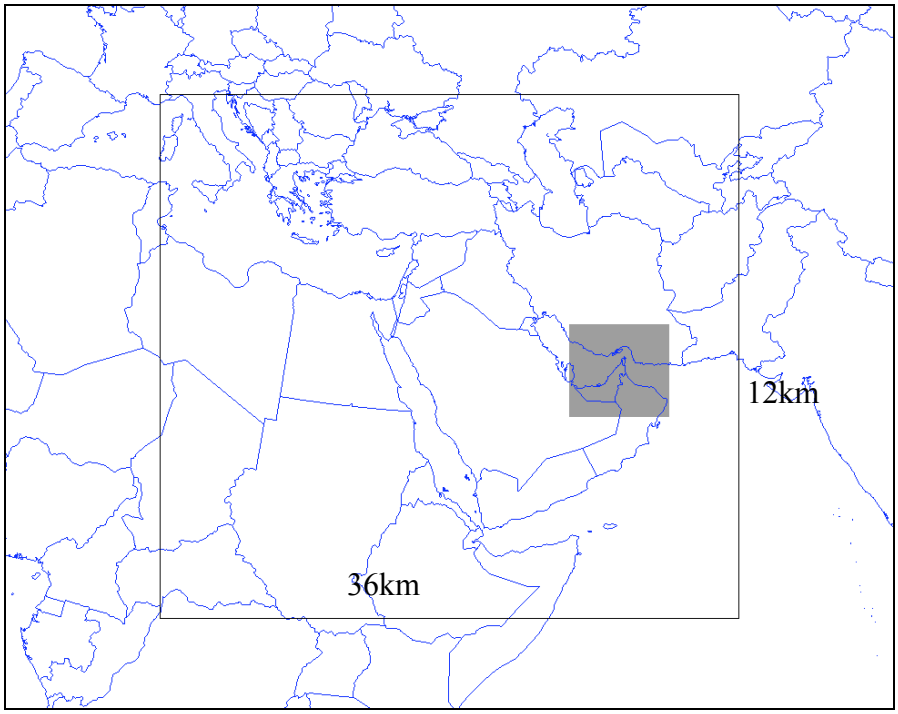

Figure 1. UAE CMAQ modeling domains

BODY

Methods

The emissions inventories for this study were compiled from multiple global, regional, and local databases. Using the Global Emissions Inventory Activity (GEIA) Center as the starting point, the inventories were assessed for their support of the objectives of an air quality modeling study to support a burden of disease assessment for the UAE. The inventories needed to cover the range of anthropogenic and biogenic emissions sources required for regional air quality modeling, be appropriate for regional-to-urban spatial scale modeling (<= 50x50 km), and as nearly represent 2007 emissions levels as possible. To satisfy the multi-pollutant configuration of CMAQ, they needed to contain oxidant and secondary PM precursor gases, primary anthropogenic PM, mercury, and air toxics. In order to support regional and local source attribution analysis, the inventories also must have vertically-resolved emissions up to the maximum plume height, source-specific PM and volatile organic compound (VOC) speciation profiles, and reasonably well-characterized source-specific temporal profiles. Because no single inventory satisfied all of these requirements, a Middle Eastern emissions modeling platform (ME-EMP) for the years 2007 and 2008 was developed from a combination of inventory and ancillary emissions data sources.

Inventories

The anthropogenic emissions in the ME-EMP were represented by a combination of the Climate Change and Impact Research: The Mediterranean Environment (CIRCE) year 2005 country-level inventory (van Aardenne, 2009), the Emissions Data for Global Atmospheric Research (EDGAR) 3.2 fast track year 2000 country-level inventory (Olivier et al., 2005), the European Monitoring and Evaluation Program (EMEP) year 2006 50-km gridded inventory, and a year 2004 point source inventory for industrial sources in Abu Dhabi, UAE (Bohler and Endregard, 2003). The CIRCE, EDGAR, and EMEP inventories present all emissions sources as column totals and require the application of vertical distribution profiles for some inventory sectors, such as energy generation and manufacturing. Annual pollutant totals were calculated from the Abu Dhabi point source inventory and subtracted from the UAE totals in the CIRCE inventory to avoid double counting of the emissions from these sources. The Model of Emissions of Gases and Aerosols from Nature (MEGAN) version 2.04 was used to estimate biogenic emissions (Guenther et al, 2006). A highly parameterized windblown dust model (SimpleDust) that uses predicted hourly horizontal winds and global land cover was used to estimate emissions from dust events. The year 2006 1º gridded, 8-day averaged Global Fire Emissions Database (GFED) version 2 was used for biomass burning emissions (van der Werf, G.R. et al, 2006). Anthropogenic mercury emissions were represented by the year 2000 Arctic Monitoring and Assessment Program (AMAP) country-level inventory (Pacyna et al, 2006). The University of Delaware (UD-Ship) 2001 gridded commercial shipping inventory at 0.1º-resolution was used for offshore sources (Wang, C. et al., 2007). Table 1 summarizes the inventories that were used in the ME-EMP. Table 2 lists the pollutants contained in each inventory.

Horizontal and Vertical Spatial Distributions

Allocating the inventories to the 36-km and 12-km air quality modeling grids was accomplished by either linear interpolation for the gridded inventories or by using GIS-developed spatial surrogates for the country-level inventories. After converting the ASCII form of the distributed gridded inventories to netCDF format (see Adelman et el, 2008), the Input/Output Applications Programming Interface (I/O API) grid-to-grid linear interpolation utility MTXCALC was used with a 100x100 refinement ratio to interpolate the gridded inventories to the modeling grids (Coats, C., 2009). Spatial surrogates were developed with the Spatial Allocator (IE, 2008b) to distribute the country-level inventories to the modeling grids using global and local GIS datasets. Table 3 summarizes the spatial surrogates that were developed for the ME-EMP emissions. Table 4 lists the surrogate assignments that were created to allocate the inventory data to the modeling grids.

Selected industrial and energy sources in the CIRCE, EMEP, and EDGAR inventories were distributed to the vertical model layers using EMEP profiles (Simpson et al., 2003). Table 5 lists the vertical profiles used to allocate the anthropogenic emissions to the vertical model layers. Biomass burning emissions were distributed through the lower 2 km of the model grid, with 25% of the emissions allocated to surface layer (0-50 m) and the remaining emissions allocated to the model layers between 50 m and 2 km.

Table 1. Middle East emissions modeling platform inventories

Sector	Europe	Africa	Middle East	Eurasia	UAE
Stationary Area	EMEP	CIRCE+ EDGAR	CIRCE	CIRCE	CIRCE
Onroad Mobile	EMEP	CIRCE+ EDGAR	CIRCE	CIRCE	CIRCE
Nonroad Mobile	EMEP	CIRCE+ EDGAR	CIRCE	CIRCE	CIRCE
Stationary Point	None[1]	None[1]	None[1]	N/A	Bohler and Endregard, 2003
Biogenic	MEGAN				
Biomass Burning	GFEDv2				
Commercial Shipping	UD-Ship				
Windblown Dust	SimpleDust				
Mercury	AMAP				

[1]Sources typically contained in a stationary point inventory, such as power plants and large industrial facilities, are represented in the stationary area inventory for this region.

Table 2. Middle East emissions modeling platform inventory pollutants

Inventory	Pollutants
CIRCE	CO, NOx, NMVOC[2], NH3, SO2, PEC, POC
EDGAR	CO, NOx, NMVOC[2], NH3, SO2, PEC, POC
EMEP	CO, NOx, NMVOC[2], NH3, SOx, PMC, PM2.5
AMAP	Total mercury
UD-Ship	CO, NOx, VOC, SO2, Total PM
Simple Dust	PMC, PMFINE
Bohler and Endregard, 2003	CO, NOx, VOC, SO2, PM10, PM2.5
MEGAN	CO, NO, VOC

[2] Non-methane VOC

Table 3. Middle East emissions modeling platform spatial surrogates

Surrogate	Shapefile	Source	Surrogate ID
Population	GPWV3_2005	CIESIN, 2005	1
Roads	ROADTRLL	USGS, 2009	2
0.5Roads+0.5Population	0.5*Roads+0.5*Population	Composite	3
UAE Roads	ROADNETWORK_LINS	Environment Abu Dhabi	4
0.5 UAE Roads+0.5Population	0.5*UAE Roads+0.5*Population	Composite	5
Crops	CRP200121	Guenther et al, 2006	6
Airports	AEROFACP	USGS, 2009	7
Mineral Extraction	EXTRACTP	USGS, 2009	8
Mines	MASM26	USGS, 2009	9
Industrial Sites	MISINDP	USGS, 2009	10
Railroads	RAILRDL	USGS, 2009	11
Storage Tanks	STORAGEP	USGS, 2009	12
Energy Utilities	UTILP	USGS, 2009	13
Unpaved Roads	ROADTRLL	USGS, 2009	14
Nonroad Mobile	0.4*Crops+0.125*Airports+ 0.125*Railroads+0.125*Mines+ 0.125*Mineral Extraction+ 0.1*Unpaved Roads	Composite	15
0.75Industrial+0.25Population	0.75*Industrial Sites+0.25*Population	Composite	17
Energy Industry	0.25*Storage Tanks + 0.75*Energy Utilities	Composite	19
Heavy Industry	0.75*Industrial Sites+0.25*Energy Industry	Composite	18
Water Utilities	UTILP	USGS, 2009	20
Waste	0.5*Population+0.5*Water Utilities	Composite	21

Table 4. Spatial surrogate assignments

Source Code	Description	Surrogate	VOC Profile
AMAPHG01	Stationary Fuel Combustion Hg	19	N/A
AMAPHG02	Metal Production Hg	18	N/A
AMAPHG03	Cement Hg	18	N/A
AMAPHG04	Chlor-alkali Hg	18	N/A
AMAPHG05	Gold Production Hg	17	N/A
AMAPHG06	Waste and Other Hg	21	N/A
AMAPHG07	Cremation Hg	1	N/A
AMAPHG08	Other Sources Hg	1	N/A
EDGARB10	Biofuel Combustion: Industrial	18	0000
EDGARB20	Biofuel Combustion: Power Generation	13	0000
EDGARB40	Biofuel Combustion: Residential	1	0000
EDGARB51	Biofuel Combustion: Road Transport	2	0000
EDGARF10	Fossil Fuel Combustion: Industrial	18	0000
EDGARF20	Fossil Fuel Combustion: Power Generation	13	0000
EDGARF30	Fossil Fuel Combustion: Other Transformation	18	0000
EDGARF40	Fossil Fuel Combustion: Residential/Commercial	1	0000
EDGARF51	Fossil Fuel Combustion: Road Transport	2	1101
EDGARF54	Fossil Fuel Combustion: Nonroad Land Transport	15	1101
EDGARF80	Fossil Fuel Production/Transmission: Oil	19	0000
EDGARF90	Fossil Fuel Production/Transmission: Gas	19	0000
EDGARI10	Industrial Processes and Solvents: Iron&Steel	18	0000
EDGARI20	Industrial Processes and Solvents: Other Metals	18	0000
EDGARI30	Industrial Processes and Solvents: Chemicals	18	0000
EDGARI40	Industrial Processes and Solvents: Building Materials	1	0000
EDGARI50	Industrial Processes and Solvents: Paper and Pulp	18	0000
EDGARI60	Industrial Processes and Solvents: Food	1	0000
EDGARI70	Industrial Processes and Solvents: Misc.	1	0000
EDGARI90	Industrial Processes and Solvents: Misc. Industry	18	0000
EDGARL43	Agriculture: Agriculture Waste Burning	16	8746
EDGARW40	Waste Handling: Incineration	21	0122
EDGARW50	Waste Handling: Miscellaneous	21	0122
CIRCEAGR	Agriculture	16	0000
CIRCEAWB	Agriculture Waste Burning	16	8746
CIRCEENG	Energy Industry	19	0000
CIRCEMNF	Manufacturing Industry	18	0000
CIRCENRD	Non-road Transport	15	1101
CIRCERES	Residential	1	0000
CIRCEORD	Road Transport	3	1101
CIRCESLV	Solvents	17	0000
CIRCEWST	Waste	21	0122

Table 5. Distribution of anthropogenic emission sectors by height (%)

	Emissions Height (m)					
Source Category	**0-92**	**92-184**	**184-324**	**324-522**	**522-781**	**781-1106**
Combustion in energy and transformation	0	0	8	46	29	17
Non-industrial combustion	50	50				
Combustion in manufacturing	0	4	19	41	30	6
Production Processes	90	10				
Fossil Fuel Extraction	90	10				
Solvent and other product use	100					
Road transport	100					
Other mobile sources	100					
Waste	10	15	40	35		
Agriculture	100					

Temporal Allocation

The temporal allocation profiles for the sources in the ME-EMP were developed from data distributed from the EMEP website (http://www.ceip.at) and by the US EPA NEI. With the 36-km modeling domain covering 3 different continents and over 50 countries, differences in weekends and holidays had to be considered carefully. For the European countries, weekends were modeled as Saturday and Sunday. For UAE, weekends were modeled as Friday and Saturday. For the rest of the 36-km modeling domain, weekends were modeled as Thursday and Friday. Only UAE holidays were considered in the preliminary model simulations, and were treated as Saturdays (the UAE equivalent of Sundays in the U.S).

Chemical Speciation

Conversion of the anthropogenic VOC inventories to Carbon Bond-05 (CB05) chemical species was accomplished with profiles obtained from the EPA. Assignments to the inventory sources were made through comparisons of the US NEI source classification code (SCC) descriptions to the descriptions of the inventory sources in the ME-EMP. Table 4 lists the VOC profile assignments used for this study. Descriptions of the VOC profiles are available online through the EPA SPECIATE Data Browser (http://projects.pechan.com/ttn/speciate/). Chemically inert tracer species profiles for benzene, formaldehyde, and acetaldehyde were developed by adding mass fractions for these pollutants into the standard CB05 speciation profiles used in the ME-EMP. Although these toxic tracers are not mass conserving, they are being treated as chemically inert tracers in CMAQ to compute preliminary exposure fields of these pollutants. Speciation of the AMAP total mercury inventory into elemental, divalent, and particulate mercury was accomplished with sector-specific speciation factors provided on the AMAP website (http://amap.no/Resources/HgEmissions/). The MEGAN biogenic VOC emissions were speciated with CB05 profiles included with the model.

Evaluation

Comparisons of the domain total SMOKE output emissions for individual source sectors and the total of all sources were compared to comparable published global and regional inventories to validate the magnitudes of the emissions. Qualitative comparisons to satellite observations for NO_2, HCHO, and aerosols are being used to confirm the accuracy of the spatial and temporal distributions of the emissions. Full evaluation of these emissions will not be completed until they are used in CMAQ simulations and the results of the air quality modeling are compared to surface and satellite air quality observation networks.

Results

The tables and figures in this section summarize the preliminary results from a May 2007 simulation of the ME-EMP. The tabulated and graphical results presented here are developed from emissions covering only the 36-km grid shown in Figure 1 unless noted otherwise. The regional and country totals presented in this section for the areas outside of the Middle East represent only a fraction of the total emissions for each region or country, proportional to the spatial coverage in the 36-km modeling domain. Table 6 presents inventory sector totals for May 2007. The area inventory is divided into four sub-sectors: residential and solvents, waste, manufacturing, and energy. The reason for dividing the area inventory was to facilitate the application of sector-specific vertical profiles (Table 5). The EMEP inventories contain inventory sub-sectors that overlap with the rest of the regions in the modeling domain; these include energy, manufacturing, agriculture, residential, onroad mobile, nonroad mobile, and waste. However, because they were modeled as pre-gridded data rather than country totals, the EMEP inventory was treated as an explicit inventory sector. Table 7 presents regional emissions totals for the different parts of the 36-km modeling domain.

Figures 2 and 3 show the May 2007 country total emissions for NOx and VOC, respectively. Figure 4 is a mosaic of pollutant pie charts showing the contribution of each inventory sector to the May 2007 domain total emissions for many of the inventory pollutants. Figure 5 includes tile plots of daily column total emissions for NO and isoprene for two days in May 2007 on the 36-km and 12-km ME-EMP modeling grids.

Table 6. May 2007 36-km grid sector totals (tons/month)

Sector	CO	NOX	VOC	NH_3	SO_2	PMC	PMFINE	PEC	POC	HG
Area (Res+Solv)	740902	41585	124562	1124	40933	0	0	11507	21651	0
Area (Waste)	0	1	53	0	0	0	0	0	0	0
Area (Manuf)	92006	77112	4608	895	184633	0	0	259	379	0
Area (Energy)	38130	179946	1074202	114	207390	0	0	347	152	0
Agriculture	76570	10645	4409	154070	344	0	0	564	2697	0
Onroad	1405980	248825	286008	1091	36761	0	0	7989	5674	0
Nonroad	14869	9399	3315	1	557	0	0	113	90	0
Shipping	6634	30712	3367	0	28992	146	341	5355	1219	0
Point	1905	12893	2724	0	25253	119	41	27	25	0
Biogenic	837013	63348	7544905	0	0	0	0	0	0	0
Biomass Burning	1185487	40211	65899	534	1007	55830	0	8410	60478	0
Windblown Dust	0	0	0	0	0	28624349	8073535	0	0	0
Europe (EMEP)	111600	19840	63634	7161	25947	7440	14477	787	1562	0
Mercury (AMAP)	0	0	0	0	0	0	0	0	0	13

Table 7. Regional emissions totals for the 36-km modeling grid

	CO	NOX	VOC	NH3	SO2	PMC	PMFINE	PEC	POC	HG
Region	Tg/yr	Tg/yr	Tg/yr	Tg/yr	Tg/yr	Tg/yr	Tg/yr	Gg/yr	Gg/yr	Gg/yr
Africa	22.07	1.69	49.49	0.85	0.82	91.76	25.77	192.79	633.30	0.01
Europe	5.43	0.48	15.42	0.24	0.08	11.44	3.31	25.22	136.20	0.09
Eurasia	4.94	0.66	7.57	1.34	0.24	117.89	33.24	26.46	125.48	0.02
Middle East	14.43	4.32	22.23	2.79	0.60	84.59	23.86	69.62	73.72	0.02

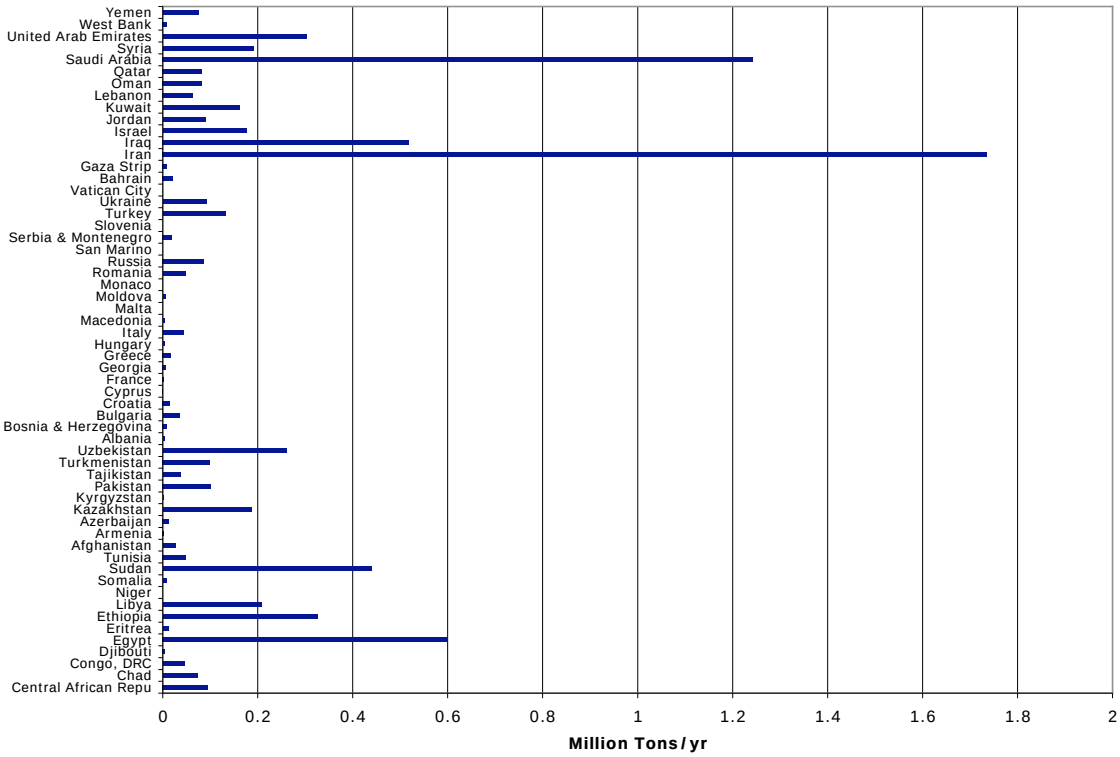

Figure 2. May 2007 NOx emissions, 36-km Middle East domain

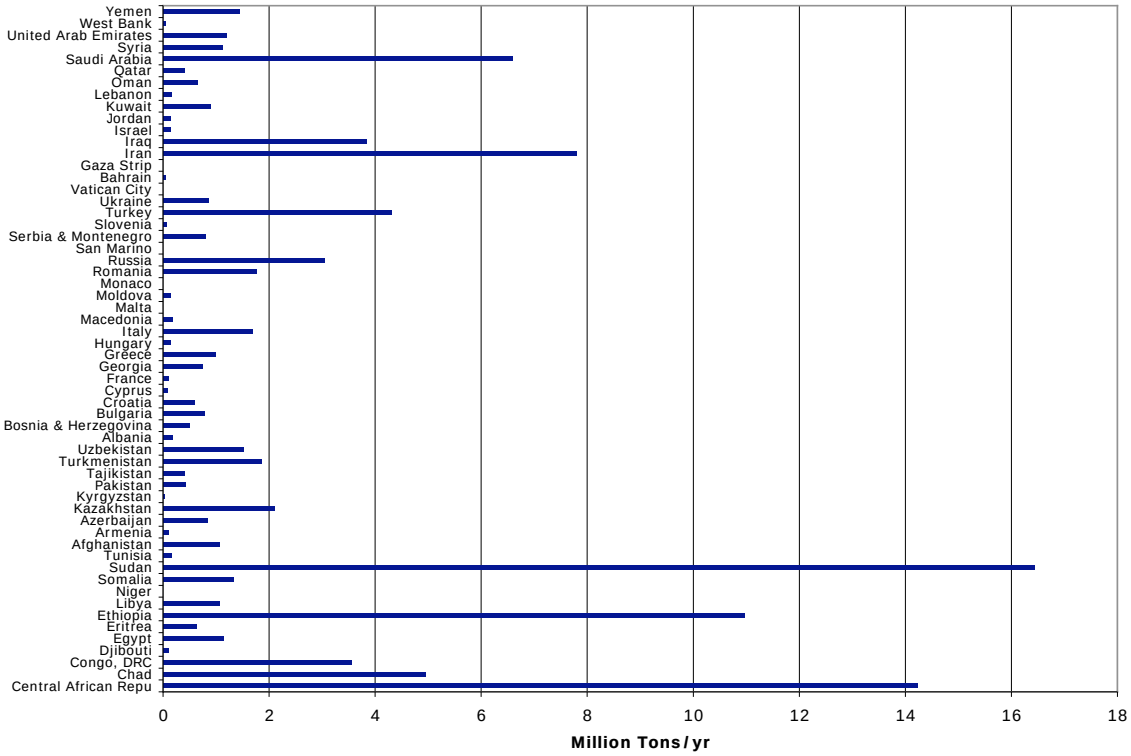

Figure 3. May 2007 VOC emissions, 36-km Middle East domain

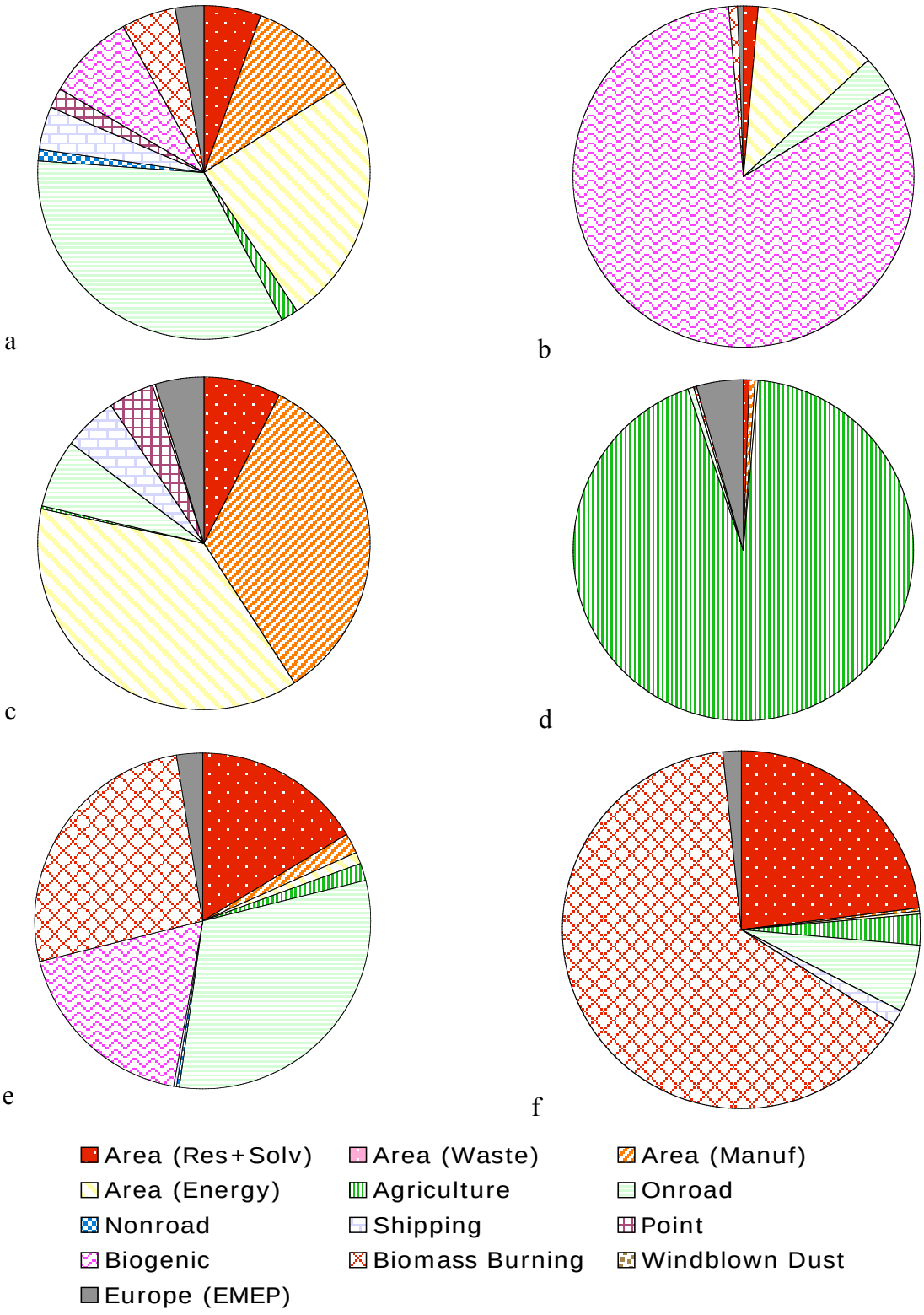

Figure 4. 36-km ME-EMP emissions sector distribution a) NOx b) VOC c) SO_2 d) NH_3 e) CO f) POC

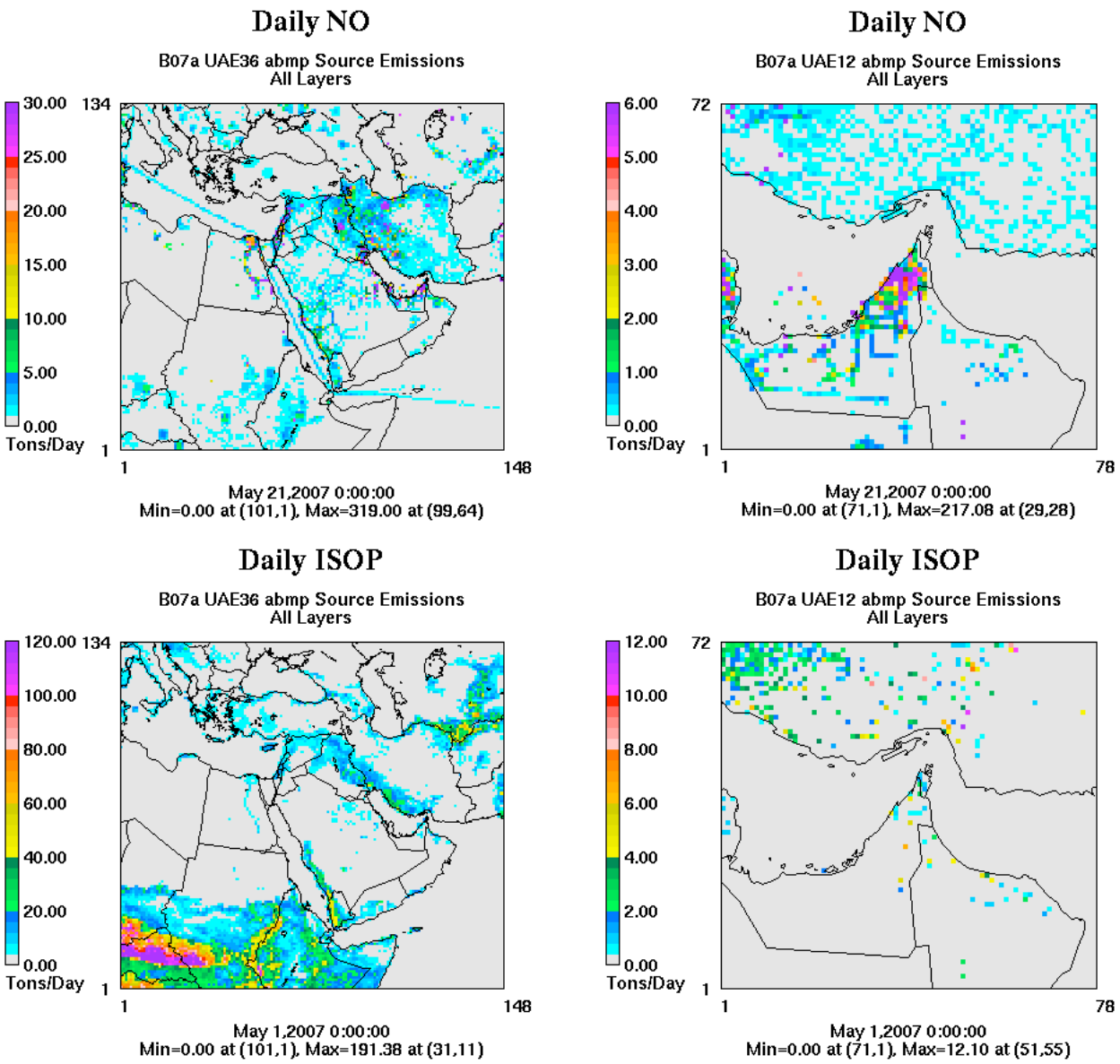

Figure 5. Daily tile plots of 36-km (left) and 12-km (right) NO (top) and isoprene (bottom) emissions

Discussion

The SMOKE results presented here are from a prototype simulation that will be used in CMAQ version 4.7 to begin to assess air quality problems in the Middle East and the UAE. Complete evaluation of these emissions will be conducted during diagnostic evaluation of the CMAQ results using comparisons between the model predictions and observational data from surface and satellite networks. Additional iterations of these emissions to correct problems discovered during the CMAQ evaluations and to include improved or missing inventories will be made and included in additional CMAQ simulations.

Qualitative comparisons of the preliminary emissions presented here are shown in Figures 6 through 8. Figure 6 compares monthly column total NO_2 emissions from SMOKE to SCIAMACHY imagery (http://envisat.esa.int/instruments/sciamachy/) of monthly mean tropospheric column NO_2. A visual comparison of these plots shows that the SMOKE emissions capture the Middle Eastern, Eurasian, and African NO_2 spatial distribution quite well, including the shipping channel emissions that the satellite tracks in the Mediterranean Sea and going through the Suez Canal into the Red Sea. The

NO_2 signal in Central Africa in the Southwestern corner of the modeling domain is from biomass burning and appears to coincide with elevated NO_2 observations from SCIAMACHY. The primary deficiency in the SMOKE emissions illustrated in these plots is in the Persian Gulf and the European countries. Limited information about offshore oil and gas activities in the Persian Gulf has inhibited the generation of emissions inventories for this sector. SCIAMACHY illustrates that this is a region of high NOx emissions that are not well represented in the SMOKE plot. Further, Rome, Italy and Istanbul, Turkey are areas of high NO_2 in the SCIAMACHY imagery that do not show up in the SMOKE emissions. The Persian Gulf oil and gas inventory and EMEP data are two emissions sectors that will be reviewed in the next iteration of these emissions.

Figure 7 compares monthly column total isoprene emissions from SMOKE to OMI imagery (http://www.knmi.nl/omi) of monthly mean column formaldehyde (HCHO). As a degradation product from VOC oxidation, HCHO has been used as a proxy to assess the accuracy of VOC emissions estimates (Palmer et al., 2006; Fu et al., 2007). While the referenced studies present techniques to use observed HCHO columns to quantitatively constrain VOC emissions estimates, the OMI imagery is being used here to crudely assess the spatial distribution of the emissions estimates. The distribution of the SMOKE emissions agrees with the OMI HCHO observations of the large isoprene peak in Central Africa highlighted in both plots. Other areas of elevated isoprene on the east coast of the Black Sea, through southeast Iraq, and the southwest tip of Yemen also show up in both plots. As a degradation product of most organic oxidation reactions, HCHO is an imprecise tracer for isoprene. The elevated HCHO over the Mediterranean shown in OMI is likely from photochemical smog being transported out of Europe and not related solely to isoprene emissions. Further, the elevated HCHO observed in Central Africa is coincident with a region of high biomass burning emissions, which were shown by Fu et al., (2007) to be detectable by HCHO column measurements.

Figure 8 compares a monthly column total sum of course mode PM (PMC) and primary organic aerosol carbon (POC) emissions from SMOKE to OMI imagery of monthly mean ultraviolet (UV) aerosol index (AI). PMC and POC were chosen to represent windblown dust and biomass burning emissions from SMOKE, respectively. AI uses the UV absorbing properties of some aerosols to provide a measure of PM from dust, smoke, black carbon, and urban smog. AI can be used to qualitatively assess the spatial and temporal distributions of estimates of emissions from windblown dust and biomass burning. AI can only give a regional approximation of dust and fire emissions because it includes the influences on emissions of physical and chemical processes, such as transport and photochemistry. Using monthly mean AI also masks short-term episodic dust and fire events that can have significant influence on air quality. Despite these inconsistencies between the SMOKE and OMI plots presented in Figure 8, there is an obvious problem with SimpleDust over predicting dust emissions around the Aral Sea during May 2007. Although Simple Dust also appears to be under predicting aerosols through central Africa and the Arabian Peninsula, further investigation of the daily emissions shows that the SimpleDust model may be producing acceptable estimates of dust emissions for some parts of the modeling domain.

The elevated AI observations through central Africa in the May 2007 monthly average OMI image in Figure 8 is likely due to transported dust from the central Sahel region of Africa. Figure 9 shows a plume of dust originating on the Western edge of the plot and traveling across central Africa during a three-day period in May 2007. The SimpleDust model emissions estimates for the 36-km modeling grid would not be expected to reproduce these AI observations because they appear to originate outside of the modeling domain. Further investigation of this issue will be conducting during analysis of the CMAQ modeling results generated with these emissions. Figure 10 shows a comparison between daily total SimpleDust estimates and OMI daily average AI for May 16, 2007. The elevated dust emissions predicted by the SimpleDust model in northern Saudi Arabia are correlated to an elevated

plume of aerosols observed by the OMI AI, indicating relatively good temporal and spatial accuracy in the SimpleDust predictions.

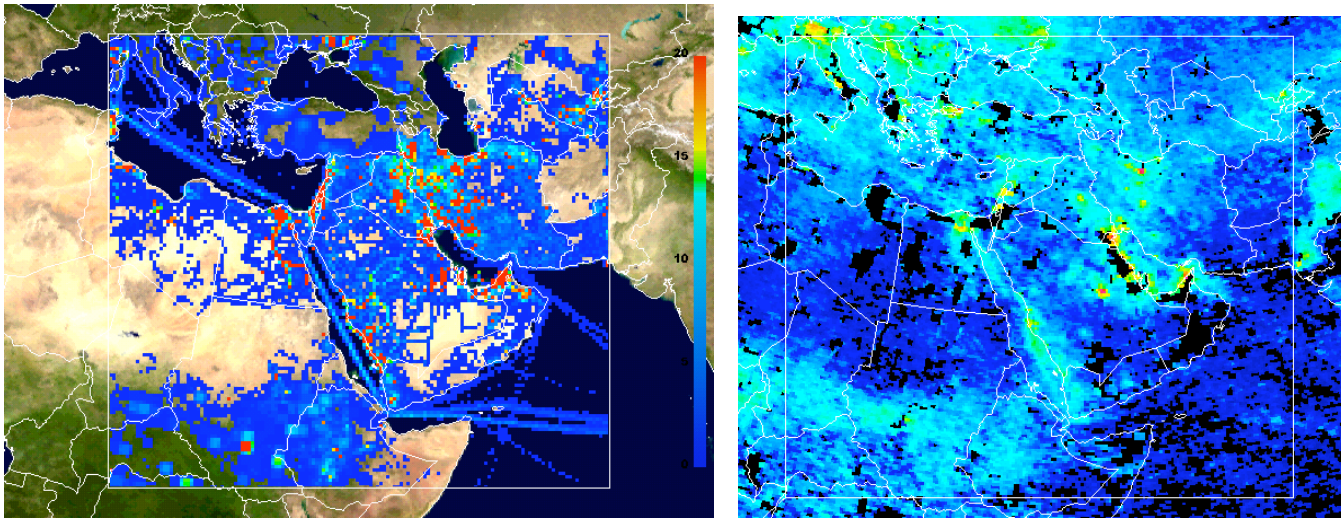

Figure 6. May 2007 total SMOKE NO2 (l); SCIAMACHY monthly mean column NO2 (r)

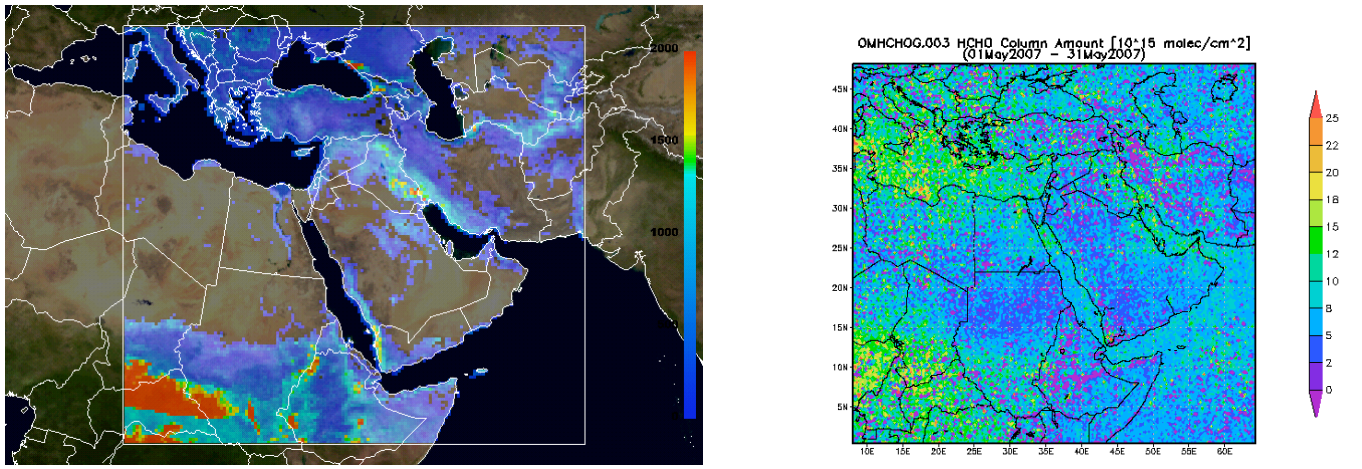

Figure 7. May 2007 total SMOKE isoprene (l); OMI monthly mean column HCHO (r)

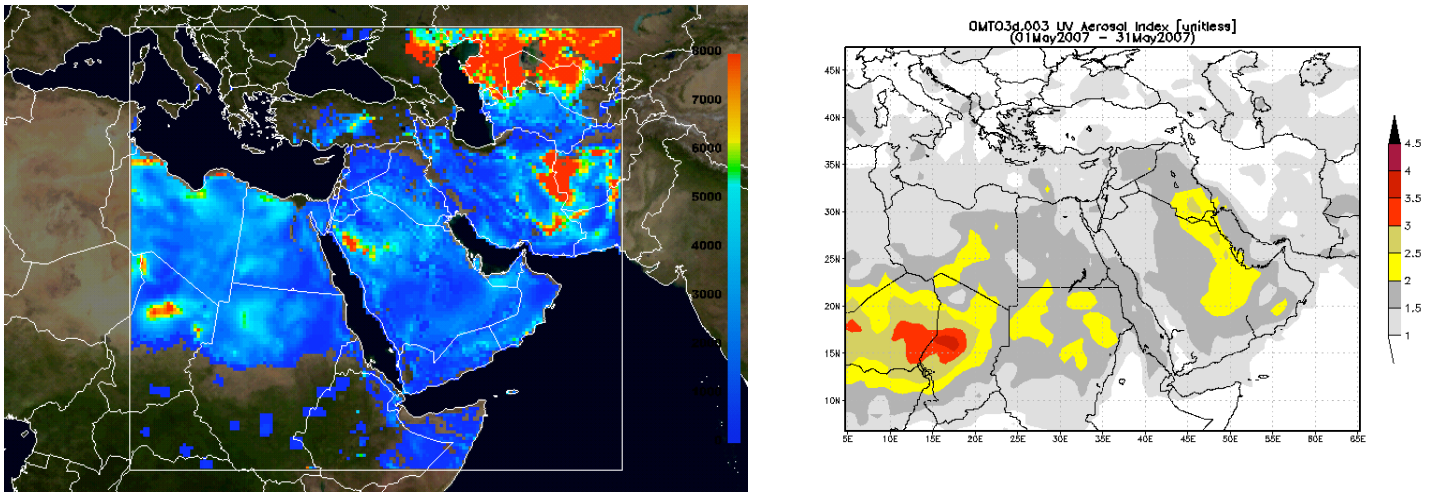

Figure 8. May 2007 total SMOKE PMC+POC emissions (l); OMI UV aerosol index (r)

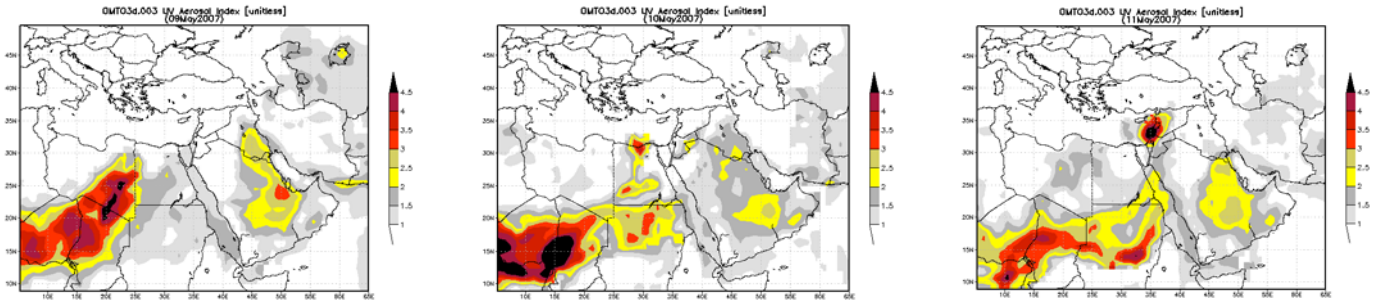

Figure 9. OMI average daily UV AI for May 9, 10, 11, 2007

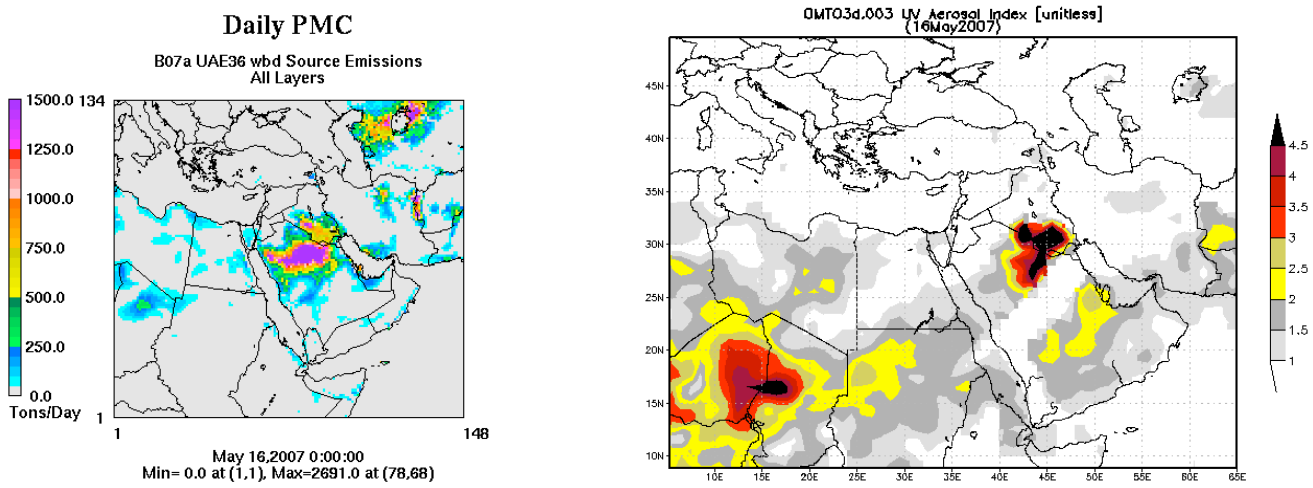

Figure 10. May 16, 2007 SMOKE daily total windblown dust PMC emissions (l); OMI daily average UV AI (r).

CONCLUSIONS

The data and emissions processing framework of the ME-EMP is an example of how emission estimates for multi-pollutant, regional modeling can be developed for parts of the world where local emissions data are sparse. The SMOKE emissions presented in this paper are prototype results for modeling air quality in the Middle East during summer 2007 and winter 2008. The sector, regional, and country totals presented here are preliminary and should not be used beyond the reporting of the emissions magnitudes used in this iteration of the ME-EMP. Full evaluation of these emissions will be conducted during the analysis of CMAQ simulations using quantitative and qualitative comparisons to surface and satellite air quality monitoring networks. Future work to improve these emissions will include the addition of vertically resolved lightning NOx emissions, results from alternative windblown dust emissions models, augmentation of the oil and gas inventories in and around the Persian Gulf, and the inclusion of local temporal and speciation profile data.

REFERENCES

Adelman, Z., A. Eyth, L. Ran. "Converting Gridding Invntories to ORL Format for Processing with SMOKE", Presented at the 17th Annual International Inventory Conference of the U.S. Environmental Protection Agency, Portland, OR, May 2008.

Ajjaji, R., A.A. Al-Katheri, A. Danhani. "Implementation and Preliminary Tests of an Air Quality Forecasting System Based on WRF-Chem over Middle East, Arabian Peninsula, and United Arab Emirates", Presented at the 8th WRF Users Workshop, Boulder, CO, 2008.

Bohler, T., G. Endregard. "Draft Final Report: Abu Dhabi Air Quality Management Study", Prepared for the UAE Environmental Research and Wildlife Development Agency by the Norwegian Institute for Air Research (NILU), Norway, 2003.

Byun, D.W., J.K.S. Ching. *Science Algorithms of the Community Multscale Air Quality Modeling System*, U.S. EPA, Washington D.C., 1999; EPA/600/R-99/030.

Byun, D.W., K.L, Schere. "Review of the Governing Equations, Computational Algorithms, and Other Components of the Models-3 Community Multiscale Air Quality (CMAQ) Modeling System". Appl. Mech. Rev. 2006, 59, pp. 51-77.

Fu, T. et al. "Space-based Formaldehyde Measurements as Constraints on Volatile Organic Compound Emissions in East and South Asia and Implications for Ozone, J. Geophys. Res 2007, 112, D06312.

Center for International Earth Science Information Network (CIESIN), Columbia University; and Centro Internacional de Agricultura Tropical (CIAT). *Gridded Population of the World Version 3 (GPWv3): Population Grids*. Palisades, NY: Socioeconomic Data and Applications Center (SEDAC), Columbia University. Available at http://sedac.ciesin.columbia.edu/gpw. 2005.

Coats, C. *Input/Output Applications Programming Interface User's Guide,* Available at http://www.baronams.com/products/ioapi, Raleigh, NC, 2009.

Guenther, A., T. Karl, P. Harley, C. Wiedinmyer, P. I. Palmer, and C. Geron. "Estimates of Global Terrestrial Isoprene Emissions Using MEGAN (Model of Emissions of Gases and Aerosols from Nature), Atmos. Chem. Phys. 2006, 6, pp. 3181-3210.

Institute for the Environment (IE), *Sparse Matrix Operator Kernel Emissions system User's Guide*, Available at http://www.smoke-model.org. Chapel Hill, NC, 2008a.

Institute for the Environment (IE), *Spatial Allocator User's Guide*, Available at http://www.ie.unc.edu/cempd/projects/mims/spatial. Chapel Hill, NC, 2008b.

Lelieveld, J., P. Hoor, P. Jöckel, A. Pozzer, P. Hadjinicolaou, and J.-P. Cammas. "Severe Ozone Air Pollution in the Persian Gulf Region". Atmos. Chem. Phys. Discuss. 2008. 8, pp. 17739-17762.

Li, Qinbin et al. "Tropospheric Ozone Maximum Over the Middle East." Geophys. Res. Lett. 2001, 28, 17, pp. 3235–3238.

Pacyna, E.G., J.M. Pacyna, F. Steenhuisen, S. Wilson. "Global anthropogenic mercury emission inventory for 2000." Atmospheric Environment, 2006, 40, 22, pp. 4048-4063.

Palmer, P. I., et al., "Quantifying the seasonal and interannual variability of North American isoprene emissions using satellite observations of the formaldehyde column." J. Geophys. Res. 2006, 111, D12315.

Prospero, J. M., P. Ginoux, O. Torres, S. E. Nicholson, and T. E. Gill, "Environmental characterization of global sources of atmospheric soil dust identified with the NIMBUS 7 Total Ozone Mapping Spectrometer (TOMS) absorbing aerosol product." Rev. Geophys., 2002, 40(1), pg. 1002.

UCB (United States Census Bureau – International Data Base), http://www.census.gov/ipc/www/idb/, Accessed March, 2009

USGS (United State Geological Survey), Global GIS Database, Available at http://webgis.wr.usgs.gov/globalgis/index.html, Accessed January, 2009.

Simpson D., H. Fagerli, J.E. Jonson, S. Tsyro, P. Wind, J. Tuovinen, "Transboundary Acidification, Eutrophication, and Ground Level Ozone in Europe – Part I: Unified EMEP Model Description." EMEP Status Report 2003, ISSN 0806-4520, 2003.

Van Aardenne, J., 2009. European Commission – Joint Research Center, Italy, *personal communication*

van der Werf GR, Randerson JT, Giglio L, Collatz GJ, Kasibhatla PS, Arellano AF. "Interannual variability in global biomass burning emissions from 1997 to 2004", Atm. Chem and Phys. 2006, 6, pp. 3423-3441.

Washington, R.,M. Todd, N.J. Middleton, A.S. Goudie, "Dust-Storm Source Areas Determined by the Total Ozone Monitoring Spectrometer and Surface Observations, Annals of the Association of American Geographers." 2003, 93, 2, pp. 297-313.

Wang, C., J.J. Corbett, and J. Firestone, "Improving Spatial Representation of Global Ship Emissions Inventories." Environmental Science & Technology. 2007.

Wheeler, N.J.M., S.B. Reid, "Photochemical Modeling of an Industrial City in Qatar", Presented at the 5th Annual CMAS Conference, Chapel Hill, NC, 2006.

KEY WORDS

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