Assessing the Anthropogenic Fugitive Dust Emission Inventory and Temporal Allocation using an Updated Speciation of Particulate Matter

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Abstract

Crustal materials are mainly emitted by anthropogenic and windblown fugitive dust, but also may potentially include some fly ash and industrial process emissions which are chemically similar to crustal emissions. Source apportionment studies have shown that anthropogenic fugitive dust emissions contribute on the order of 5-20% of PM2.5 (particles with an aerodynamic diameter less than 2.5 um) and 40-60% of PM10 (particles with an aerodynamic diameter less than 10 um) in urban areas that either have been or potentially may be unable to attain the National Ambient Air Quality Standards (NAAQS) for PM2.5 and/or PM10. On the other hand, air quality models suggest vastly higher contributions from current fugitive dust emission inventories, with contributions ranging from 50-80% for PM2.5 and 70-90% for PM10. These estimates are from a Desert Research Institute workshop report from May 2000 that is available from EPA's Technology Transfer Network Clearinghouse for Inventories & Emissions Factors. This paper uses an improved speciation of the particulate matter to include, in addition to the current PM species, eight trace metals as well as separate non-carbon organic matter to assess potential improvements to the emission estimates of anthropogenic fugitive dust. The source categories of emissions from fugitive dust include unpaved road dust, paved road dust, commercial construction, residential construction, road construction, agricultural tilling, livestock operations, and mining and quarrying.

Introduction

The NARSTO 2005 assessment report stressed that emissions are at the cornerstone of air quality management decision-making. While the United States Environmental Protection Agency (EPA), Office of Air Quality Planning and Standards (OAQPS) bears the responsibility for maintaining the National Emissions Inventory (NEI) for traditional anthropogenic sources (e.g., electrical generating units and mobile sources), many nontraditional emission categories (such as fugitive dust) remain poorly characterized after gridding, temporal allocation, and speciation are performed for input into a chemical transport model in an emissions processing system. Our Air Quality modeling system consists of several components that are dependent on each other: A National Emission

Inventory, an Emissions Processing System, a Chemical Transport Model, and a meterological driver. Non-point fugitive dust emissions are currently estimated in the National Emissions Inventory on a county-level annual basis. Fugitive dust categories of interest include unpaved and paved road dust, dust from highway, commercial and residential construction, agricultural tilling, livestock operations, and mining and quarrying. Since the NEI does not include information about temporal or spatial allocation and this information is needed in chemical transport modeling applications, we need to account for the physical processes and that drive the emission estimates needed on an hourly time scale and on the grid scale in our emission processing system. Currently, there is no adjustment for near-source removal due to small sub-grid scale turbulence and impaction on building and vegetative surfaces. Pace (2005) estimated that local source removal typically account for 75% removal of fine particulate matter nationally and defined this removal factor as a “Capture Fraction”. The amount that is not removed is defined as the “transportable fraction.” Unpaved road dust is the highest single emissions category within the nonpoint fugitive dust category, accounting for about one third of non-windblown fugitive dust emissions. This is followed in importance by dust from tilling, quarrying and other earthmoving. A transportable fraction as proposed by Pace (2005) is applied on a per county basis to both PM10 and PM2.5. In addition, the current temporal allocation in the emissions processing system (not the NEI) assumes no monthly variability and no weekday/weekend variation. In essence, each day is represented identically throughout the year. This paper summarizes two phases to improve and diagnose the fugitive dust emission estimates used in chemical transport modeling. The first phase involves improvements to the transportable fraction applied to the gridded emission inventory field and improvements to the temporal allocation of the fugitive dust emissions. The second phase involves a new way to diagnose the PM2.5 from all sources by tracking eight trace metals. These trace metals are then modeled in a chemical transport model and compared with ambient measurements. This allows for better source attribution of measured trace metals.

Spatial and Temporal Improvements to the Inventory

In Pace (2005), the transportable fraction , (i.e. the amount that is not “captured” by near-source removal), is calculated on a per county basis for 3 Regional Planning Organizations using the Biogenic Emission Inventory System (BEIS) version 2 county-level land use information Byun and Ching (1999)]). The western states, (WRAP and CENRAP) are calculated using a different land use database, the North American Landcover Dataset 2000 (NALC 2000). The North America Land Cover (NALC) for the year 2000 (Latifovic, et al. 2002) was developed jointly by the Natural Resources Canada - Canada Centre for Remote Sensing and the USGS EROS Data Center as part of the larger Global Land Cover 2000 project implemented by
the Global Vegetation Monitoring Unit of the Joint Research Center (JRC) of the European Commission. In this paper, we have recalculated the transportable fraction at a 1km resolution using the newer BELD3 database (Vukovich and Pierce, 2002) for all of the contiguous US. The transportable fraction is calculated for five broad land use categories (Forest, Urban, Sparsely wooded & Grass, agricultural, and barren/water).

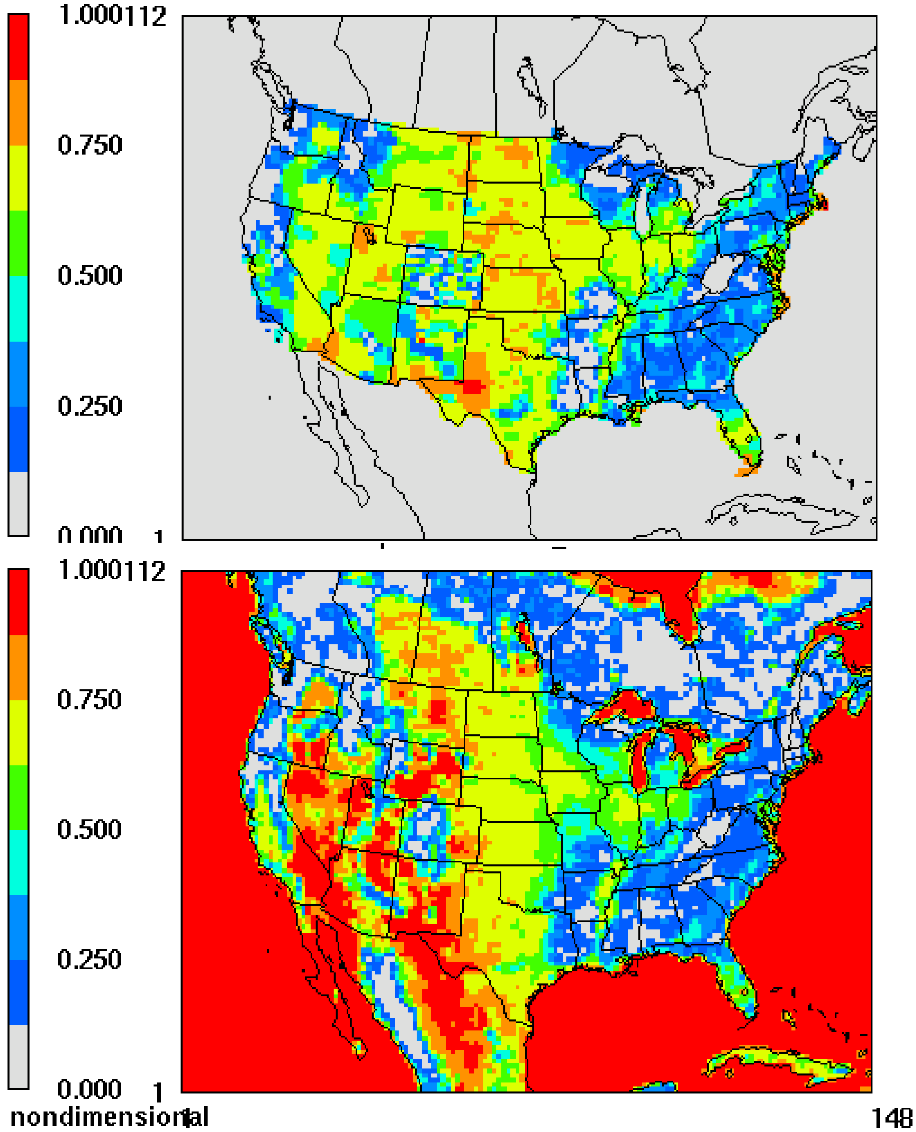
Table 1 shows the mapping of the BELD3 land use types to the five broad land use categories and the associated capture fraction.

Table 1: BELD3 categories, Capture Fraction Class, and Transportable Fraction

BELD3 category	Capture Fraction class	Transportable Fraction
USGS_urban	Urban	0.50
USGS_drycrop	Grass	0.75
USGS_irrcrop	Grass	0.75
USGS_cropgrass	Grass	0.75
USGS_cropwdlnd	Grass	0.75
USGS_grassland	Grass	0.75
USGS_shrubland	Water/Barren	1.00
USGS_shrubgrass	Grass	0.75
USGS_savanna	Grass	0.75
USGS_decidforest	Forest	0.05
USGS_evbrdleaf	Forest	0.05
USGS_coniferfor	Forest	0.05
USGS_mxforest	Forest	0.05
USGS_water	Water/Barren	1.00
USGS_wetwoods	Forest	0.05
USGS_sprsbarren	Water/Barren	1.00
USGS_woodtundr	Grass	0.75
USGS_mxtundra	Water/Barren	1.00
USGS_snowice	Water/Barren	1.00
All Agriculture classes	Grass	0.75
All tree classes	Forest	0.05

This provides a consistent method across the lower 48 states as well as a more accurate representation of the land cover. Figure 1 shows the revised transportable fraction as calculated using the revised methodology and compared to Pace (2005). This resulted in both increases and decreases in the transportable fraction but a better spatial representation.

Figure 1. (a) Transportable Factor from Tom Pace(2005) (b) Revised Transportable Factor using BELD3



Temporal activity factors are used to distribute emissions throughout the year. A second improvement to the methodology is to modify the temporal activity factors used in the emissions processing. The source categories of emissions from fugitive dust include unpaved road dust, paved road dust, commercial construction, residential construction, road construction, agricultural tilling, livestock operations, and mining and quarrying. For each of these categories, revisions are made to the monthly, weekly, and daily temporal profiles. The rationale for these temporal allocation changes is that we have activity factors for associated sectors that differ from the activity factors that have been assumed for the fugitive dust emissions. An example of this is agricultural tilling. We have a temporal profile for the combustion emissions of agricultural equipment in the non-road mobile source sector that is different than the fugitive dust emissions from agricultural tilling. We harmonized the temporal factors for each the fugitive dust sectors with other components of the emission inventory and processing platform where appropriate and summarize our proposed changes. Table 2 shows the changes made to the temporal allocation factors for each of the source categories of interest along with the 2002 NEI emission totals for each source category.

Table 2: Temporal Allocation Improvements. A Green means no change. A Red means Updated to match temporal allocations already in use for non-dust sources.

Source Classification Code Description	2002 NEI PM2.5(Tons/yr)	monthly	weekly	daily
Mobile Sources;Aircraft;Unpaved Airstrips;Total	3	X	X	X
Mobile Sources;Paved Roads;All Paved Roads;Total: Fugitives	122,452	X	X	X
Mobile Sources;Unpaved Roads;All Unpaved Roads;Total: Fugitives	840,572	X	X	X
Mobile Sources;Unpaved Roads;Public Unpaved Roads;Total: Fugitives	1,816	X	X	X
Mobile Sources;Unpaved Roads;Industrial Unpaved Roads;Total: Fugitives	16	X	X	X
Industrial Processes;Construction: SIC 15 - 17;All Processes;Total	2,749	X	X	X
Industrial Processes;Construction: SIC 15 - 17;Residential;Total	19,339	X	X	X
Industrial Processes;Construction: SIC 15 - 17;Residential;Ground Excavations	133	X	X	X
Industrial Processes;Construction: SIC 15 - 17;Industrial/Commercial/Institutional;Total	60,015	X	X	X
Industrial Processes;Construction: SIC 15 - 17;Industrial/Commercial/Institutional;Ground Excavations	101	X	X	X
Industrial Processes;Construction: SIC 15 - 17;Road Construction;Total	116,958	X	X	X
Industrial Processes;Mining and Quarrying: SIC 14;All Processes;Total	120,493	X	X	X
Miscellaneous Area Sources;Agriculture Production - Crops;Agriculture - Crops;Total	990	X	X	X
Miscellaneous Area Sources;Agriculture Production - Crops;Agriculture - Crops;Planting	415	X	X	X
Miscellaneous Area Sources;Agriculture Production - Crops;Agriculture - Crops;Tilling	536,006	X	X	X
Miscellaneous Area Sources;Agriculture Production - Crops;Agriculture - Crops;Harvesting	484	X	X	X
Miscellaneous Area Sources;Agriculture Production - Crops;Agriculture - Crops;Loading	7	X	X	X
Miscellaneous Area Sources;Agriculture Production - Livestock;Agriculture - Livestock;Total	1,213	X	X	X
Miscellaneous Area Sources;Agriculture Production - Livestock;Beef cattle - finishing operations on feedlots (drylots);Dust Kicked-up by Hooves (use 28-05-020, -001, -002, or -003 for Waste	17,450	X	X	X

Speciation Changes to the Inventory

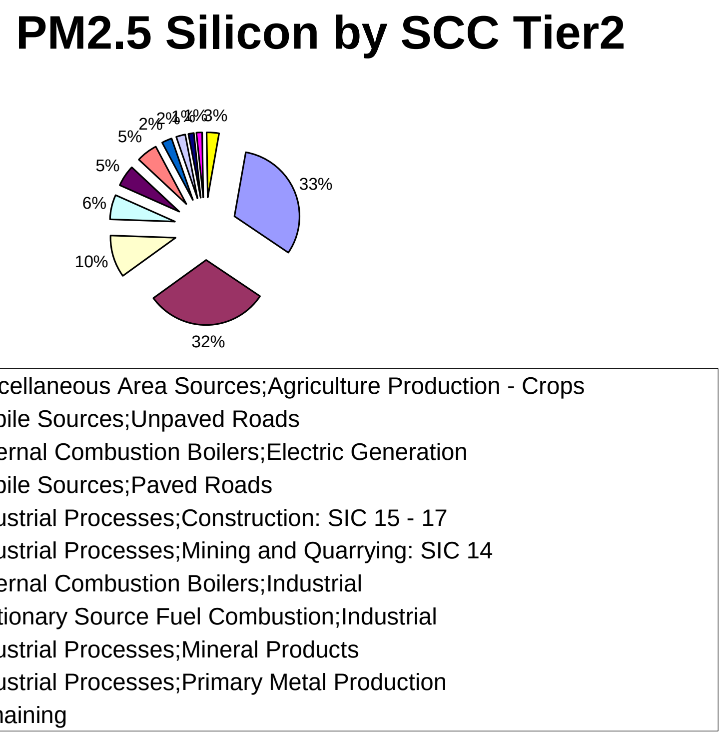
In the second phase, we updated the speciation of PM2.5 from all sources including the dust sources. These updates to the speciation of PM2.5 were made possible as a result of the work of Reff et al (2009). In this paper, an inventory for trace metals from PM2.5 was derived using EPA's SPECIATE database and compared to ground-based measurements in the Contiguous US. Composite PM2.5 profiles containing the trace metals were then mapped to all available source classification codes. The miscellaneous component of PM2.5 (aka PMFINE) was broken down into 14 components. These 14 components are shown in Table 3.

Table 3: The Revised Speciation of PMFINE and the reasons for making them explicit.

New Species	Description	Reason
PH20	Particulate Water associated with Ammonium Sulfate	Already explicit in CMAQ
PCL	Chloride	Already explicit in CMAQ
PNA	Sodium	Already explicit in CMAQ
PNH4	Ammonium	Already explicit in CMAQ
PNCOM	Non-Carbon Organic Matter (Reff et. al., 2009)	to accurately model total organic mass
PCA	Calcium	For modeling thermodynamic partitioning, and for crustal matter
PSI	Silicon	To represent crustal matter
PMG	Magnesium	For modeling thermodynamic partitioning
PMN	Maganese	For modeling aqueous reactions
PAL	Aluminum	To represent crustal matter
PFE	Iron	To represent crustal matter & for modeling aqueous reaction
PTI	Titianium	To represent crustal matter
PK	Pottasium	For modeling thermodynamic partitioning
PMOTHR	Remaining PM2.5 Mass	Remaining part of PMFINE (renamed)

With this new speciation, we are now able to view the emission inventory in much more detail. We can see which groups of Source Classification Codes are associated with particular trace metals. For example, 89% of Silicon inventory in the unadjusted 2002 National Emissions Inventory is dominated by six sources: agricultural tilling, unpaved road dust, External Combustion Boilers (from Electric Generating Units), Paved Road Dust, construction, and mining and quarrying. Of these six sources, five of them are in the nonpoint source fugitive dust inventory. Although Silicon is not a tracer for a particular source classification code (SCC), we can use the revised speciation to assess groups of sources and evaluate them in our chemical transport modeling system. Figure 2 shows the fraction of Silicon from different source sectors at the Source Classification Code Tier 2 level.

Figure 2: Percentage of Silicon by SCC Tier 2 catergory for the 2002 NEI.



Preliminary Results

The Community Multiscale Air Quality (CMAQ) photochemical transport model v4.7.1 (Byun and Schere, 2006) was modified with an updated aerosol module to incorporate the PM2.5 species listed in Table 3. This new CMAQ version was used to study the impact of the changes to the emissions processing on the predicted ambient PM2.5 concentrations. We ran three scenarios of the chemical transport model: (1) without any area source fugitive dust sources but included the revised speciation (2) with area source fugitive dust sources and the revised speciation but no temporal or spatial updates from phase 1 (3) with all the changes in phase 1 and phase 2. We then compared the trace particulate compounds

Figure 3: Scatter plots of for the Observed vs CMAQ Silicon (μg/m^3) for January and July 2002 no dust case

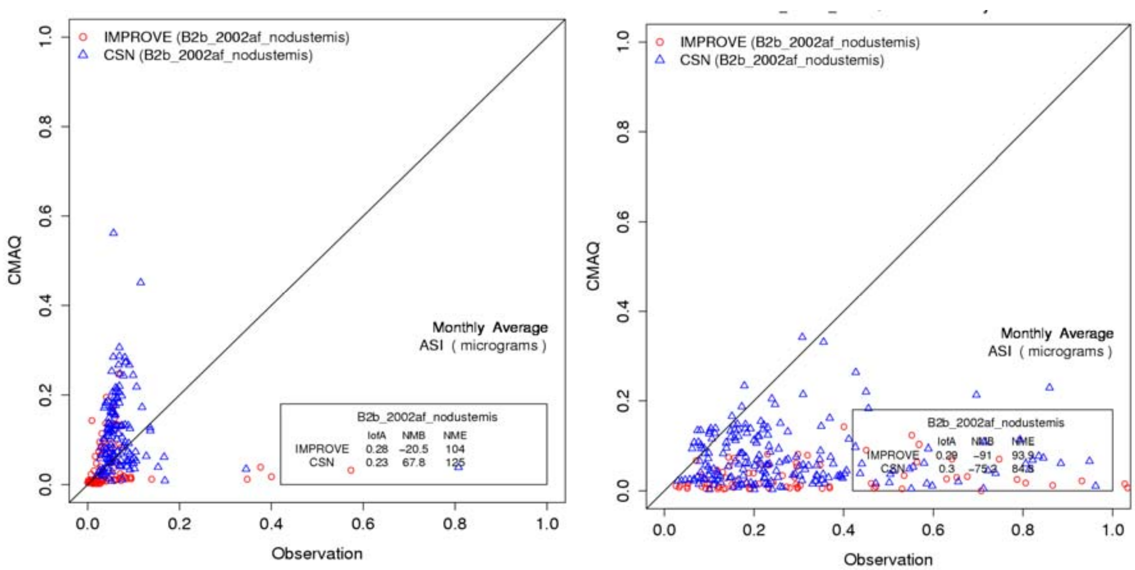


Figure 4: Scatter plots of for the Observed vs CMAQ Silicon (μg/m^3) for January and July 2002 with dust included.

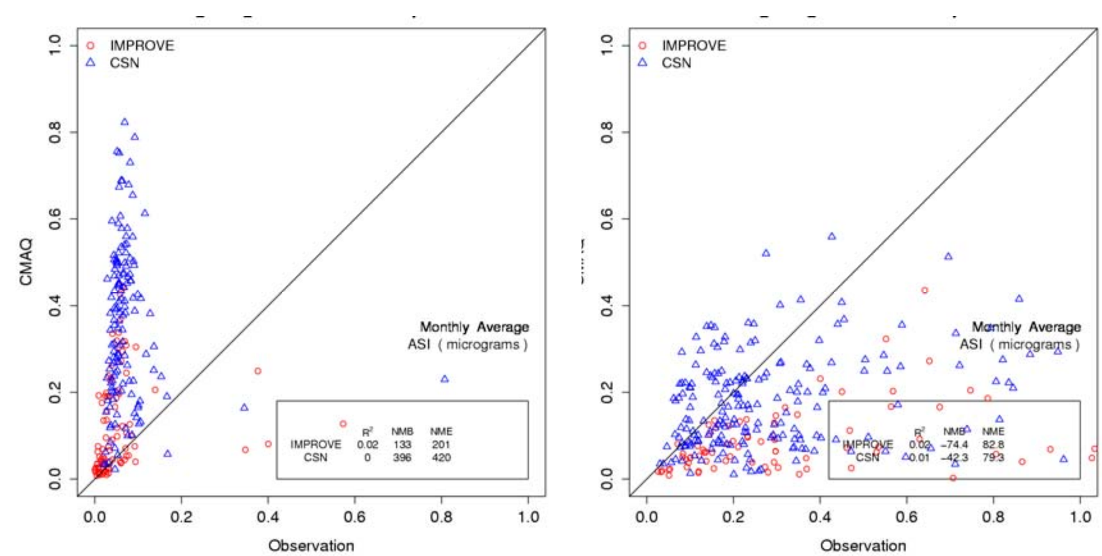
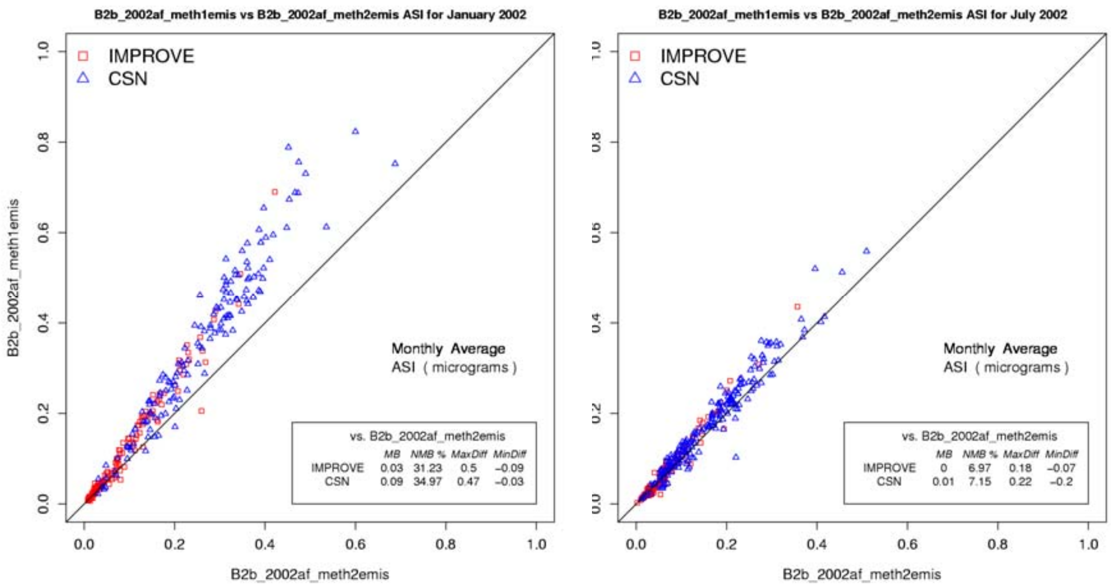


Figure 5 : Model to Model Comparison for January and July 2002 for Silicon (μg/m^3) with the changes discussed in phase 1.



Discussion

By revising the speciation profiles from PM2.5 to include trace metals that are readily measured at monitoring locations, we are able to study the impact of changes to the emission inventory processing (temporal allocation and transportable fraction), and begin to make improvements to our emission inventory. Using Silicon as an example, we see that the model has a high bias for Silicon in the winter by a factor of 10. We can then go to our inventory by SCC code and trace metals to see that the high bias in the winter is due to at least 2 causes: overestimates of Silicon from the External Combustion Boilers (from Electric Generating Units and from fugitive dust. We can then look for improvements to specific source categories by reviewing the methods and assumptions associated with a particular SCC. Figure 2 demonstrates that across the board adjustments to the dust emissions are not appropriate since elimination of dust emissions does not completely fix the wintertime over-estimates of silicon but causes a significant under-estimation in the summer. For Silicon, we see that Agricultural Tilling is overestimated in the winter probably because the inventory estimate does not account for or poorly accounts for the meteorological effects of snow and rainfall on agriculture tilling. We plan to modify the emission estimates for this source category significantly by accounting for meteorological effects in the emission processing. We expect the impact of this change to be more significant in the winter because only snowfall occurs in the winter months and the rainfall impact will be smaller in the summer because the soil drys out faster and thus more dust can be generated under warmer conditions.

Summary

This paper summarizes initial work to improve the speciation of the particulate matter in order to assess potential improvements to the emission estimates of anthropogenic fugitive dust (unpaved and paved road dust, dust from highway, commercial and residential construction and agricultural tilling). We included proposed changes to the fugitive dust emission processing as well as how we plan to ascertain which components of the emission inventory can be improved using a detailed speciation of PM2.5 in a chemical transport model. Updates to CMAQ to incorporate these speciation changes will be included in the next release of CMAQ.

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Keywords

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