ENVIRON ALPINE GEOPHYSICS UNC INSTITUTE FOR THE ENVIRONMENT

March 11, 2013

TECHNICAL MEMORANDUM No. 6: DUST SOURCE EMISSIONS

To: Tom Moore, Western Regional Air Partnership (WRAP)

From: Zac Adelman, University of North Carolina/Institute for the Environment
Ralph Morris, ENVIRON International Corporation
Cyndi Loomis, Alpine Geophysics, LLC

Subject: Dust Emission Sources for the WestJumpAQMS 2008 Photochemical Modeling

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INTRODUCTION

ENVIRON International Corporation (ENVIRON), Alpine Geophysics, LLC (Alpine) and the University of North Carolina (UNC) at Chapel Hill Institute for Environment are performing the West-wide Jump Start Air Quality Modeling Study (WestJumpAQMS) managed by the Western Governors' Association (WGA) for the Western Regional Air Partnership (WRAP). WestJumpAQMS is setting up the CAMx photochemical grid model for the 2008 calendar year (plus spin up days for the end of December 2007) on a 36 km CONUS, 12 km WESTUS and several 4 km Inter-Mountain West domains. The WestJumpAQMS Team are currently compiling emissions to be used for the 2008 base case modeling, with the 2008 National Emissions Inventory (NEI) being a major data source, and are preparing 13 Technical Memorandums discussing the sources of the 2008 emissions by major source sector:

1. Point Sources including Electricity Generating Units (EGUs) and Non-EGUs;
2. Area plus Non-Road Mobile Sources;
3. On-Road Mobile Sources that will be based on MOVES;
4. Oil and Gas Sources;
5. Fires Emissions including wildfire, prescribed burns and agricultural burning;
6. Dust Sources including fugitive, windblown, and road dust;
7. Off-Shore Shipping Sources;
8. Ammonia Emissions;
9. Biogenic Emissions;
10. Eastern USA Emissions (dropped, covered in other memos);
11. Mexico/Canada;

12. Sea Salt and Lightning Emissions; and
13. Emissions Modeling Parameters including spatial surrogates, temporal adjustment parameters and chemical (VOC and PM) speciation profiles.

This document is Technical Memo Number 6 that discusses the approach and data sources to be used for developing 2008 emissions for the dust emission sources.

2008 NEI V2.0 OVERVIEW

The U.S. Environmental Protection Agency (EPA) develops and maintains the National Emissions Inventory (NEI). The NEI is a comprehensive and detailed estimate of air emissions of both Criteria and Hazardous air pollutants from all air emissions sources in the United States. The NEI is prepared every three years by the EPA based primarily upon emission estimates and emission model inputs provided by State, Local, and Tribal air agencies for sources in their jurisdictions, and supplemented by data developed by the EPA. The most current version of the NEI is Version 2 of the 2008 NEI (2008 NEIv2) that we obtained from EPA at the end of February 2012[1]. The fugitive and road dust inventories were extracted from the 2008 NEIv2 non-point source inventory. As windblown dust (WBD) emissions are calculated with a meteorology-based model, the WRAP WBD Model was used with the hourly 2008 WRF meteorology (ENVIRON and Alpine, 2012[2]).

Dust Emission Inventories

EPA defines fugitive dust as "small particles of geological origin that are suspended into the atmosphere from non-ducted emitters."[3] This general definition includes particle emissions from wind erosion, roads, parking lots, construction sites, open pits and mines, agricultural fields, and material transfer operations. As an emissions inventory component, dust emission sources are typically accounted for as non-point sources, which mean that they are estimated as annual, state or county total emissions by source. For example, an inventory may report the total annual emissions in short tons per year of particulate matter with a diameter of < 2.5 µm ($PM_{2.5}$) from unpaved roads in Clark County, Nevada. In the WestJumpAQMS we define three principal categories of dust emissions: (1) windblown dust; (2) paved and unpaved road dust; and (3) all other dust sources resulting from the mechanical disturbance of soils. We use the term fugitive dust to refer to this last category of other dust sources (e.g., dust from agricultural, mining, and construction activities). Additional sources of dust-like particles, such as break and tire wear and industrial sources, such as gypsum and cement plants, are included in the on-road mobile and point source inventory sectors.

For the WestJumpAQMS, dust includes only those sources of particles resulting from the natural or mechanical disturbance of the surface of the earth; particle emissions from industrial processes and vehicle components (brakes and tires) are not included in the definition of dust for this study. Table 1

1 http://www.epa.gov/ttnchie1/net/2008inventory.html
2 http://www.wrapair2.org/pdf/WestJumpAQMS_2008_Annual_WRF_Final_Report_February29_2012.pdf
3 Watson, J.G., J.C. Chow, T.G. Pace (2000) Fugitive Dust Emissions. *Air Poll. Eng. Man.*

lists the inventory source classification codes (SCCs) included in the WestJumpAQMS road dust and fugitive dust inventories. These non-point sources of dust are quantified as annual, county total emissions. Windblown dust, or particle emissions resulting from wind-driven soil disturbance, is estimated with a process-based model that uses simulated hourly meteorology parameters and land-cover data to simulate dust fluxes over a pre-defined modeling grid. Details of the three WestJumpAQMS dust categories and how these data are prepared for emissions modeling are included in the next sections.

Table 1. Road and fugitive dust SCCs in the 2008 NEIv2.

2275085000	Mobile Sources;Aircraft;Unpaved Airstrips;Total
2294000000	Mobile Sources;Paved Roads;All Paved Roads;Total: Fugitives
2296000000	Mobile Sources;Unpaved Roads;All Unpaved Roads;Total: Fugitives
2296005000	Mobile Sources;Unpaved Roads;Public Unpaved Roads;Total: Fugitives
2296010000	Mobile Sources;Unpaved Roads;Industrial Unpaved Roads;Total: Fugitives
2311000000	Industrial Processes;Construction: SIC 15 - 17;All Processes;Total
2311010000	Industrial Processes;Construction: SIC 15 - 17;Residential;Total
2311010040	Industrial Processes;Construction: SIC 15 - 17;Residential;Ground Excavations
2311010070	Industrial Processes;Construction: SIC 15 - 17;Residential;Vehicle Traffic
2311020000	Industrial Processes;Construction: SIC 15 -17; Industrial/Commercial/Institutional; Total
2311020040	Industrial Processes;Construction: SIC 15 - 17;Industrial/Commercial/Institutional; Ground Excavations
2311030000	Industrial Processes;Construction: SIC 15 - 17;Road Construction;Total
2325000000	Industrial Processes;Mining and Quarrying: SIC 14;All Processes;Total
2801000000	Miscellaneous Area Sources;Agriculture Production - Crops;Agriculture - Crops;Total
2801000002	Miscellaneous Area Sources;Agriculture Production - Crops;Agriculture - Crops;Planting
2801000003	Miscellaneous Area Sources;Agriculture Production - Crops;Agriculture - Crops;Tilling
2801000005	Miscellaneous Area Sources;Agriculture Production - Crops;Agriculture - Crops;Harvesting
2801000007	Miscellaneous Area Sources;Agriculture Production - Crops;Agriculture - Crops;Loading
2801000008	Miscellaneous Area Sources;Agriculture Production - Crops;Agriculture - Crops;Transport
2805000000	Miscellaneous Area Sources;Agriculture Production - Livestock;Agriculture - Livestock; Total
2805001000	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
2805001300	Miscellaneous Area Sources;Agriculture Production - Livestock;Beef cattle - finishing operations on feedlots (drylots);Land application of manure
2805002000	Miscellaneous Area Sources;Agriculture Production - Livestock;Beef cattle production composite;Not Elsewhere Classified
2805018000	Miscellaneous Area Sources;Agriculture Production - Livestock;Dairy cattle composite; Not Elsewhere Classified
2805020000	Miscellaneous Area Sources;Agriculture Production - Livestock;Cattle and Calves Waste Emissions;Total

Road Dust

Road dust sources represent particle emissions resulting from vehicles traveling on roadways or across parking lots. The road dust inventory is split between paved and unpaved roads. Descriptions of the emissions factors for each of these sources of road dust and how these emissions factors were applied for the 2008 NEIv2 are described below. The documentation of the road dust inventories relies heavily on the paved and unpaved road dust technical support documents associated with the 2008 NEI. These documents are available from the EPA ftp site.[4]

Paved Roads

The 2008 NEI assigns SCC 2294000000 (Mobile Sources; Paved Roads; All Paved Roads; Total: Fugitives) to paved road dust sources. The current EPA AP-42 emission factors for paved roads (January 2011) include only the resuspension of loose material on the road surface as the source of dust. According to the AP-42, "resuspended particulate emissions from paved roads originate from, and result in the depletion of loose material present on the surface (i.e. surface loading)."[5] Several processes exist to replenish the surface loading and road dust emissions occur when the equilibrium between depletion and surface loading is upset. The AP-42 emission factor for paved roads is dependent on the size of the particles on the road surface (k), the surface silt loading (sL), and the average weight of the vehicles traveling on the road (W):

$$E = k\,(sL)^{0.91} \times (W)^{1.02} \times [1-P/(4N)] \qquad (1)$$

Where: E = size-specific PM emission factor (mass/VMT)
k = particle size multiplier for particle size range and units of interest (mass/VMT)
sL = road surface silt loading (g/m^3)
W = average weight (tons) of vehicles traveling on the road
P = number of days in the year with at least 0.01 inches of precipitation
N = number of days in the year.

Equation (1) was derived from a stepwise regression of 83 profile emissions tests and deliberately excludes the direct emission of particles from exhaust, brake wear, and tire wear. The paved road dust emissions estimated with Equation (1) are intended to be combined with an on-road mobile source emission model (i.e. MOVES) that estimates exhaust, brake wear, and tire wear PM emissions. Additional details about the derivation of Equation (1) are available in Chapter 13 of the AP-42, Volume I, Fifth Edition.[3]

The following text is taken entirely from the 2008 NEI technical support document for paved road dust and provides detailed information on how the basic AP-42 emission factor equation was applied to estimate paved road dust emissions for the 2008 NEIv2.[6]

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4 ftp://ftp.epa.gov/EmisInventory/2008_nei/nonpoint/
5 http://www.epa.gov/ttn/chief/ap42/ch13/final/c13s0201.pdf
6 ftp://ftp.epa.gov/EmisInventory/2008_nei/nonpoint/paved_roads_rvsd090711.zip

"[For the 2008 NEIv2], uncontrolled paved road emissions were calculated at the county level by roadway type and year. This calculation was done by multiplying the county/roadway class paved road VMT by the appropriate paved road emission factor. Next, control factors were applied to the paved road emissions in counties containing PM_{10} nonattainment areas and counties with areas previously in nonattainment that now have maintenance plans. Emissions and VMT by roadway class were then totaled to the county level for reporting in the NEI.

"Paved road silt loadings were assigned to each of the twelve functional roadway classes (six urban and six rural) based on the average annual traffic volume of each functional system by State.[7] The silt loading values per average daily traffic volume come from the ubiquitous baseline values from Section 13.2.1 of AP-42. The resulting paved road silt loadings calculated from the average annual traffic volume data are shown in Table 2 [of the 2008 NEI paved roads technical support document].

"To better estimate paved road fugitive dust emissions, the average vehicle weight was estimated by road type for each county in the U.S. (plus Puerto Rico and the U.S. Virgin Islands) based on VMT data used in the 2008 on-road NEI. For state and local agencies that provided VMT data to EPA for use in the 2008 NEI, those data are included in this data set. Additionally, if a state/local agency did not provide VMT data for the 2008 NEI, but had provided information for either the 2005 or 2002 NEI, the state/local-supplied data were grown to 2008 based on 2008 VMT data from the Federal Highway Administration (FHWA). The VMT data for the remaining counties were based on 2008 Federal Highway Administration data. (See the NEI on-road documentation for more details on how the default VMT data were calculated from the FHWA data set.)

"The 2008 VMT data set from the NEI included in EPA's National Mobile Inventory Model (NMIM) BaseYearVMT table includes 2008 VMT for each county by road type and 28 MOBILE6 vehicle types. An average vehicle weight was estimated for each of these 28 vehicle types, as shown in Table 3 [of the 2008 NEI paved roads technical support document]. For the heavy-duty Class 2B through Class 7 vehicle classes, the average of the gross vehicle weight rating (GVWR) range was selected as the average weight of the vehicle class. More detailed information for the heavy-duty Class 8A and 8B vehicle classes were available from the U.S. Bureau of the Census Vehicle Inventory and Use Survey (VIUS). The Class 8A and 8B subcategories by weight from VIUS were weighted by annual mileage to estimate the average 8A and 8B average vehicle class weights. For the light-duty vehicle and truck classes, data from the U.S. Department of Energy Annual Energy Outlook 2010 were used to represent the average vehicle weights. The average weight of motorcycles and the three bus categories were estimated using professional judgment based on information about existing model weights for these vehicle classes. Once the average vehicle weight was assigned to each of the 28 MOBILE6 vehicle classes, these averages were then assigned to each VMT record in the NMIM BaseYearVMT table, corresponding to the vehicle class that the VMT represented. A VMT-weighted average vehicle weight was then calculated by county and road type for each county/road type combination in the database.

"The AP-42 equation (1) listed above includes a correction factor to adjust for the number of days with measurable precipitation in the year. The factor of "4" in the precipitation adjustment accounts for the fact that paved roads dry more quickly than unpaved roads and that precipitation may not occur over

7 U.S. Department of Transportation, Federal Highway Administration. *Highway Statistics 2008.* Office of Highway Policy Information. Washington, DC. 2011. Available at http://www.fhwa.dot.gov/policyinformation/statistics/2008/.

the entire 24-hour day period. The number of days with at least 0.01 inches of precipitation in each month by State was obtained from the National Climatic Data Center.[8] Data were collected from a meteorological station selected to be representative of urban areas within each State."

Activity

"Total annual VMT estimates by county and roadway class were derived from a 2008 NMIM run, totaling all vehicle types and speeds for each county and road type. Paved road VMT was estimated using a ratio of state-level paved road VMT to total VMT. State level paved road VMT was calculated by subtracting the State/roadway class unpaved road VMT from total State/roadway class VMT. Federal Highway Administration's (FHWA) annual Highway Statistics report was used to determine the unpaved VMT in each state.[5]"

Controls

"Paved road dust controls were applied by county to urban and rural roads in counties with serious PM_{10} nonattainment or maintenance areas and to urban roads in counties with moderate PM_{10} nonattainment or maintenance areas. The assumed control measure is vacuum sweeping of paved roads twice per month. A control efficiency of 79 percent was assumed for this control measure.[9] The assumed rule penetration varies by roadway class and PM_{10} nonattainment area classification (serious or moderate).[7] The rule penetration rates are shown in Table 4 [of the 2008 NEI paved roads technical support document]. Rule effectiveness was assumed to be 100% for all counties where this control was applied.

"Note that the controls were applied at the county/roadway class level, and the controls differ by roadway class. No controls were applied to interstate or principal arterial roadways because these road surfaces typically do not have vacuum sweeping. In the CERS submission, the emissions for all roadway classes were summed to the county level. Therefore, the emissions at the county level can represent several different control efficiency and rule penetration levels. The county/roadway class control efficiency and rule penetration levels are reported in the Controlled PM by County&Type table in the file Paved_Roads_229400000_CAP_Emissions.xlsx [which accompanies the 2008 NEI paved roads technical support document]."

Effective in the January 2011 AP-42, the $PM_{2.5}$ particle size multiplier for paved roads was revised to 25% of PM_{10}.

Unpaved Roads

The 2008 NEI assigns SCC 2296000000 (Mobile Sources; Unpaved Roads; All Unpaved Roads; Total: Fugitives) to unpaved road dust sources. Vehicles traveling on unpaved roads produce dust emissions

8 U.S. Department of Commerce, National Oceanic and Atmospheric Administration. Summary of the Day Element TD-3200, 2008 data provided via FTP. National Climatic Data Center. 2009

9 .H. Pechan & Associates, Inc. "Phase II Regional Particulate Strategies; Task 4: Particulate Control Technology Characterization," draft report prepared for U.S. Environmental Protection Agency, Office of Policy, Planning and Evaluation. Washington, DC. June 1995.

as "particles are lifted and dropped from the rolling wheels, and the road surface is exposed to strong air currents in turbulent shear with the surface."[10] Similar to the equation for paved roads, the unpaved road emission factor equation considers the sizes of particles and silt loading on the road surface. Reentrained road dust emissions for unpaved roads are estimate using the following equation from AP-42:

$$E = \frac{k\,(s/12)^{1}(S/30)^{0.5}}{\left(\frac{M}{0.5}\right)^{0.2}} - C \qquad (2)$$

Where:
E = size-specific PM emission factor (mass/VMT)
k= particle size multiplier (lb/VMT)
s = surface material silt content (%)
M = surface material moisture content (%)
S = mean vehicle speed (mph)
C = emission factor for 1980's vehicle fleet exhaust, brake wear and tire wear

Equation (2) includes the correction term (C) to exclude the direct emission of particles from exhaust, brake wear, and tire wear. The unpaved road dust emissions estimated with Equation (2) are intended to be combined with an on-road mobile source emission model (i.e. MOVES) that estimates exhaust, brake wear, and tire wear PM emissions. Additional details about the derivation of Equation (2) are available in Chapter 13 of the AP-42, Volume I, Fifth Edition.[3]

The following text is taken entirely from the 2008 NEI technical support document for unpaved road dust and provides detailed information on how the basic AP-42 emission factor equation was applied to estimate unpaved road dust emissions for the 2008 NEIv2.[11]

"Uncontrolled unpaved road emissions were calculated [with Equation (2)] at the State level by roadway class and month. This was done by multiplying the State/roadway class unpaved roadway VMT by the appropriate monthly temporal allocation factor and by the monthly unpaved road emission factor. After the unpaved road dust emissions were calculated at the State/roadway class/monthly level of detail, the uncontrolled emissions were then allocated to the county level using 1990 rural population data as a surrogate. Next, control factors were applied to the unpaved road emissions in PM_{10} nonattainment area counties. Emissions and VMT by roadway class were then totaled to the county level for reporting in the NEI.

"Average State-level unpaved road silt content values, developed as part of the 1985 NAPAP Inventory, were obtained from the Illinois State Water Survey.[12] Silt contents of over 200 unpaved roads from over 30 States were obtained. Average silt contents of unpaved roads were calculated for each state

10 http://www.epa.gov/ttn/chief/ap42/ch13/final/c13s0202.pdf
11 ftp://ftp.epa.gov/EmisInventory/2008_nei/nonpoint/roads_unpaved_epa_data.zip
12 W. Barnard, G. Stensland, and D. Gatz, Illinois State Water Survey, "Evaluation of Potential Improvements in the Estimation of Unpaved Road Fugitive Emission Inventories," paper 87-58.1, presented at the 80th Annual Meeting of the APCA . New York, New York. June 21-26, 1987

that had three or more samples for that state. For states that did not have three or more samples, the average for all samples from all states was used as a default value.

"[Mean vehicle] speeds were determined based on the average speeds modeled for on-road emission calculations and weighted to determine a single average speed for each of the roadway classes. The value of 0.5 percent for M was chosen as the national default as sufficient resources were not available at the time the emissions were calculated to determine more locally-specific values for this variable

"Correction factors were applied to the [unpaved road] emission factors to account for the number of days with a sufficient amount of precipitation to prevent road dust resuspension. Monthly corrected emission factors by state and roadway classification were calculated using the following equation:

$$E_{corr} = E * [(D-p)/D] \qquad (3)$$

Where: E_{corr} = unpaved road dust emission factor corrected for precipitation effects
E = uncorrected emission factor
D = number of days in the month
p = number of days in the month with at least 0.01 inches of precipitation

"The number of days with at least 0.01 inches of precipitation in each month was obtained from the National Climatic Data Center.[6] Data were collected from a meteorological station selected to be representative of rural areas within [each] state. The monthly precipitation data used by state for 2008 are included in Appendix C [of the 2008 NEI unpaved roads technical support document].

<u>Activity</u>

"Unpaved roadway mileage estimates were obtained from the FHWA's annual Highway Statistics report.[13] Unpaved mileage data for 2007 were used, as data for 2008 were not yet available. Separate calculations of VMT were performed for county- and noncounty- (state or federally) maintained roadways. State-level, county-maintained roadway mileage was organized by surface type (rural and urban) and the average daily traffic volume (ADTV) groups shown in Table 4 [of the 2008 NEI unpaved roads technical support document]. From these data, state-level unpaved roadway mileage estimates were made. The following equation was then used to calculate state-level unpaved road VMT estimates:

$$EMIS_{x,y} = (CL_x/SL) * EMIS_y \qquad (4)$$

Where: $EMIS_{x,y}$ = unpaved road emissions (tons) for county x and roadway class y
CL_x = rural population in county x
SL = rural population in the state
$EMIS_x$ = unpaved road emissions in entire state for roadway class y

<u>Controls</u>

13 U.S. Department of Transportation, Federal Highway Administration. *Highway Statistics 2007.* Office of Highway Policy Information. Washington, DC. 2009. Available at http://www.fhwa.dot.gov/policyinformation/statistics/2007/.

“The controls assumed for unpaved roads varied by PM_{10} nonattainment area classification and by urban and rural areas. On urban unpaved roads in moderate PM_{10} nonattainment areas, paving of the unpaved road was assumed, and a control efficiency of 96 percent and a rule penetration of 50% were applied. Chemical stabilization, with a control efficiency of 75% and a rule penetration of 50%, was assumed for rural areas in serious PM_{10} nonattainment areas. A combination of paving and chemical stabilization, with a control efficiency of 90%and a rule penetration of 75%, was assumed for urban unpaved roads in serious PM_{10} nonattainment areas.[7]

“Note that the controls were applied at the county/roadway class level, and the controls differ by roadway class. In the NIF 3.0 emissions table, the emissions for all roadway classes were summed to the county level. Therefore, the emissions at the county level can represent several different control, rule effectiveness, and rule penetration levels. As a result, the control efficiency, rule effectiveness, and rule penetration values were reported in the control equipment table as a composite, overall control level for each county; the rule effectiveness and rule penetration values were not reported separately in the emissions table.”

The AP-42 guidance is explicit about the quality of the results of equations 1 and 2 being closely tied to the correction parameters, silt loading, and the moisture content values used to calculate emissions with these equations. Site-specific values are required to maintain a high quality rating for the computed emissions. The use of default values or values that are not location-specific for these parameters will reduce the quality of the emissions estimates from these equations. Similarly, the AP-42 guidance for both paved and unpaved roads describe methods to adjust the emission factors to account for prevention and/or mitigation of the dust emissions. Additional terms for the emission factors equations to account for the impacts of precipitation on dust emissions are also presented. The 2008 NEI technical support documents for both paved and unpaved roads indicate that a combination of national-scale correction factors and location-specific parameters on roadway characteristics were used to calculate the county-level road dust emission inventory.

Effective in the January 2006 AP-42, the $PM_{2.5}$ particle size multiplier for unpaved roads was revised to 10% of PM_{10}.

Windblown Dust

Wind Blown Dust (WBD) emissions for the WestJumpAQMS were estimated using the WRAP WBD model (Mansell et al., 2006[14,15,16,17]). The WRAP WBD model uses threshold friction velocities (u_*) as a function of surface roughness (z_0) to estimate dust emissions from barren land. Hourly, gridded friction velocities for the three WestJumpAQMS modeling domains (36/12/4 km) are input to the WBD model from the WestJumpAQMS 2008 WRF meteorological model results (ENVIRON and Alpine, 2012[18]). The relationship between u_* and z_0 developed by Marticorena et al.[19], which was validated

14 http://www.wrapair.org/forums/dejf/documents/WRAP_WBD_PhaseII_Final_Report_050506.pdf
15 http://www.wrapair.org/forums/dejf/documents/AppendixA.pdf
16 http://www.wrapair.org/forums/dejf/documents/AppendixB.pdf
17 http://www.wrapair.org/forums/dejf/documents/WRAP_DEJF_WBDust_smry_060606.pdf
18 http://www.wrapair2.org/pdf/WestJumpAQMS_2008_Annual_WRF_Final_Report_February29_2012.pdf

against wind tunnel measurements (see Figure 2-1 of Mansell et al., 2006[2]), was used as the basis of the WRAP WBD model. The predicted friction velocity depends on the surface roughness and the WRF surface wind speed (u_z) at height z above the ground using the following relationship:

$$u_z/u_* = 1/\kappa * \ln(z/z_0) \quad (5)$$

Where: κ = von Karmen's constant (0.4)
u_z = wind speed at height z (m/s)
u_* = friction velocity (m/s)
z = height above ground (m)
z_0 = aerodynamic roughness height (m)

There are separate emissions factors as a function of friction velocity for disturbed versus un-disturbed land. WBD emissions are calculated for each grid cell using the fractional coverage of each land cover type within the grid cell, the friction velocity predicted by WRF in the grid cell, and the WBD emissions factor for disturbed or un-disturbed land. Fugitive Dust Transport Factors (FDTFs) are then applied to reduce the WBD emissions to account for the fact that some WBD emissions are scavenged by vegetation cover locally in the grid cell where they are emitted and are not transported. For example, barren land has a FDTF of 0.0 that means all WBD emissions are transported, whereas forested land has a WBF FDTF of 1.0 that means all of the emissions are scavenged by vegetation and none are transported away from the cell where they are emitted.

The WRAP WBD model has 6 land cover types. Agricultural land is assumed to be disturbed land and the other five categories assumed to be undisturbed land. Table 2 describes the key parameters for the six land use land cover (LULC) types in the WRAP WBD model.

Table 2. Parameters used in the WRAP WBD PM emissions model

LULC	FDTF	Disturbed	Z_0 (cm)
Barren	1.0	Un-Disturbed	0.0020
Agricultural	0.75	Disturbed	0.0310
Grassland	0.75	Un-Disturbed	0.1000
Scrubland	0.75	Un-Disturbed	0.0500
Forest	0.0	Un-Disturbed	50.0
Urban	0.0	Un-Disturbed	50.0

Note that the FDTF in Table 2 used in the WRAP WBD Model are taken from a June 2, 2005 report by Pace (2005) "Methodology to Estimate the Transportable Fraction (TF) of Fugitive Dust Emissions for Regional and Urban Scale Air Quality Analysis." However, that report was revised on August 3, 2005[20] and had one significant update that was not included in the WRAP WBD model and that was a revision of the Urban FDTF from 0.0 to 0.5. The WRAP WBD model estimates no WBD PM emissions from urban lands, using the revised FDTF there could be WBD PM emissions from urban lands. However, in

19 Marticorena, B., Bergametti, G., Gillette, D., and Belnap, J. 1997. Factors controlling threshold friction velocity in semiarid and arid areas of the United States, *J. Geophys. Res.*, 102 (D19): 23277-23287.
20 http://www.epa.gov/ttn/chief/emch/dustfractions/transportable_fraction_080305_rev.pdf

reality since urban land has such a high surface roughness value (50 cm) the threshold velocity of WBD suspension requires extremely high wind speeds so even if a positive FDTF was used there would still be almost no WBD from urban land. In addition, the fraction of urban land in the west is very small.

Initial Windblown Dust Modeling

The WRAP WBD model was used to the estimate WBD emissions using the 2008 WestJumpAQMS WRF data. As an initial quality check on these emission estimates, we compared the 2008 emissions with those generated by the WRAP Regional Modeling Center using year 2002 MM5 data. The predicted 2008 WBD PM emissions were extremely high, which we found was partially due to the 2008 WRF layer 1 (12 m) being much shallower than the 2002 MM5 layer 1 (36 m). To correct this discrepancy, we averaged the WRF lowest layer wind speeds to approximate an average 40 m layer wind speed. These averaged wind speeds still produced WBD PM emissions that were approximately three times the WBD model predictions that used the 2002 MM5 data and the layer 1 wind speeds.

For some western states the 2008 WBD emissions were ~60% of the total $PM_{2.5}$ emissions across all inventory sectors. The CAMx model performance for the other $PM_{2.5}$ (OPM2.5) species (i.e., $PM_{2.5}$ mass minus SO_4, NO_3, NH_4, OA and EC), which includes WBD emissions, exhibited an overestimation bias at IMPROVE sites where WBD made up a majority of the $PM_{2.5}$ emissions. These results suggest that the 2008 WBD estimates are likely overstated in some regions of the modeling domain. Given the uncertainties in WBD emissions modeling, the 2008 WBD emissions were reduced by a factor of 3 in an attempt to improve the model performance for dust (OPM25) and also to normalize the results with the dust predictions from the WRAP RMC 2002 modeling.

Fugitive Dust

In addition to roadways and natural windblown sources, other sources of dust include construction sites, open pits and mines, agricultural fields, and material transfer operations. While redundant because the term fugitive dust generally includes all sources of dust from "non-ducted emitters", including roads and wind-driven events, in the WestJumpAQMS it is being used to describe all "other" sources of dust in the non-point and non-road mobile inventories. Table 1 lists the SCCs and descriptions of all of the sources in the 2008 NEIv2 that we identified as dust emitters. Note that this table does not include WBD sources because these emissions were estimated from the WRAP WBD process-based model and not taken from the 2008 NEIv2. All of the sources other than the paved and unpaved road SCCs (2294* and 2296*) in Table 1 are considered fugitive dust sources and include dust emissions from airstrips, construction, mining and quarrying, and agricultural activities. This memorandum is not discussing any fugitive dust sources in the point source inventory, which may include material handling facilities at industrial sites, such as coal power plants or cement plants.

Construction

Most of the following text is taken directly from the residential, non-residential, and road construction technical support documents for the 2008 NEI[21]. Look-up tables with the parameters in equations 7 through 9 are included in these technical support documents.

21 ftp://ftp.epa.gov/EmisInventory/2008_nei/nonpoint/construction_road_res_nonres_rvsd090711.zip

"Initial PM_{10} emissions from construction of single family, two family, and apartments structures are calculated using the emission factors given in Table 3. The duration of construction activity for houses is assumed to be 6 months and the duration of construction for apartments is assumed to be 12 months."

The equation for calculating PM_{10} emissions from residential construction sources is:

$$PM_{10}\ Emissions = \sum(A_{unit} \times T_{construction} \times EF_{unit}) \times Adj_{PM} \quad (6)$$

Where: $A_{unit} = HS_{Unit} \times SM_{Unit}$
HS_{Unit} = Regional starts x (county building permits/regional building permits)
SM_{Unit} = Area or volume of soil moved for the given unit type
$T_{Construction}$ = Construction time (in months) for given unit type
EF_{Unit} = Emission factor for PM_{10} for the given unit type (tons/acre-month)
Adj_{PM} = PM Adjustment factor

Table 3. Emission Factors for Residential Construction

Type of Structure	Emission Factor	Duration of Construction
Apartments	0.11 tons PM10/acre-month	12 months
2-Unit Structures	0.032 tons PM10/acre-month	6 months
1-Unit Structures w/o Basements	0.032 tons PM10/acre-month	6 months
1-unit Structures with Basements	0.011 tons PM10/acre-month	6 months
	0.059 tons PM10/1000 cubic yards	

"Initial PM_{10} emissions from construction of non-residential buildings are calculated using an emission factor of 0.19 tons/acre-month. The duration of construction activity for non-residential construction is assumed to be 11 months. Since there are no condensible emissions, primary PM emissions are equal to filterable emissions."

The equation for calculating PM_{10} emissions from non-residential construction sources is:

$$E_{PM10} = N * (Emp_x/Emp_{Tot}) * A * EF * M \quad (7)$$

Where: N = National spending on non-residential construction ($)
Emp_x = Employment data in county x (# employees)
Emp_{Tot} = National employment (# employees)
A = Annual value of construction (acres per million dollars)
EF = PM_{10} emissions factor (0.19 tons/acre-month)
M = duration of construction activity (11 months)

"Initial PM_{10} emissions from construction of roads are calculated using an emission factor of 0.42 tons/acre-month. Since most road construction consists of grading and leveling of land, the higher emission factor more accurately reflects the high level of cut and fill activity that occurs at road construction sites. The duration of construction activity for road construction is assumed to be 12 months."

The equation for calculating PM_{10} emissions from roads is:

$$E_{PM10} = \sum(HD_{rt} \times MC_{rt} \times AC_{rt}) \times (HS_{County} / HS_{State}) \times EF_{Adj} \times M \qquad (8)$$

Where: HD_{rt} = Highway spending for a specific road type ($)
MC_{rt} = Mileage conversion for a specific road type (1000 $/mile)
AC_{rt} = Acreage conversion for a specific road type (acres disturbed/mile)
HS_{County} = Housing starts in a given county (starts)
HS_{State} = Housing starts in a given state (starts)
EF_{Adj} = Adjusted PM10 emission factor (0.42 tons/acre-month)
M = duration of construction activity (12 months)

"Regional variances in construction emissions are corrected using soil moisture level and silt content. These correction parameters are applied to initial PM_{10} emissions from non-residential construction to develop the final emissions inventory.

"To account for the soil moisture level, the PM_{10} emissions are weighted using the 30-year average precipitation-evaporation (PE) values from Thornthwaite's PE Index. Average precipitation evaporation values for each State were estimated based on PE values for specific climatic divisions within a State. These values range from 7 to 41.

"To account for the silt content, the PM_{10} emissions are weighted using average silt content for each county. A database containing county-level dry silt values was complied. These values were derived by applying a correction factor developed by the California Air Resources Board to convert wet silt values to dry silt values."

The equation for then correcting the PM_{10} emissions for soil moisture and silt content is:

$$\text{Corrected } E_{PM10} = E_{PM10} * (24/PE) * S/0.09 \qquad (9)$$

Where: Corrected E_{PM10} = PM_{10} emissions corrected for soil moisture and silt content
PE = precipitation-evaporation value for each state
S = % dry silt content in soil for area being inventoried

"Once PM_{10} adjustments have been made, $PM_{2.5}$ emissions are set to 10% of PM_{10}."

Mining & Quarrying

Unlike construction activities and road dust, there does not appear to be a technical support document for mining and quarrying emission estimates in the 2008 NEI. The emissions factors for aggregate handling and storage piles in the AP-42 currently appear to be the best documentation for these emission sources. The general derivation of these emissions described in the AP-42 is not sufficient to describe how year and location-specific parameters in the emission factor equation for these sources were derived for the 2008 NEI.

According to the AP-42 section for Aggregate Handling and Storage Piles[22], dust emissions "occur at several points in the storage cycle [of aggregate materials], such as material loading onto piles, disturbances by strong wind currents, and loadout from a pile. The movement of trucks and loading equipment in the storage pile area is also a substantial source of dust." The AP-42 includes silt and moisture contents of industrial materials for iron and steel production, stone quarrying and processing, taconite mining and processing, western surface coal mining, coal fired power plants, and municipal solid waste landfills.

The equation for calculating PM emissions from loadouts and drops of industrial materials is:

$$E = k(0.0016)\,[(U/2.2)^{1.3}/(M/2)^{1.4}] \qquad (10)$$

Where: E = emission factor (kg emissions/Mg of material transferred)
k = particle size multiplier
U = mean wind speed (m/s)
M = material moisture content (%)

Look up tables for k and M are included in the AP-42. It appears that $PM_{2.5}$ emissions are set to about 15% of PM_{10} emissions estimated from this equation.

The AP-42 recommends that dust emissions at aggregate loading and storage facilities from equipment traveling between or on piles be estimated with the unpaved road emissions equations. Similarly, it's implied that windblown emissions from these types of operations should be estimated using the AP-42 windblown dust equation (which incidentally is the same equation used in the WRAP WBD model). Given the lack of a technical support document for these sources, it's difficult to determine how Equation (9) was applied in the 2008 NEI and whether it was combined with emissions from the unpaved road and windblown dust equations to estimate total PM emissions from aggregate handling operations.

Agricultural Activities

Sources of primary PM emissions from agricultural activities include livestock operations, fertilizer application, and crops. Sources of PM from livestock operations may include feed, bedding materials, dry manure, unpaved soil surfaces, animal dander, and poultry feathers. Confinement facilities, dry manure storage sites, and land application sites are potential PM emission sources.[23] Unlike the construction and mining sectors, the AP-42 does not use equations to calculate emission factors for PM emissions from agricultural sources but instead uses factors gathered from the literature or derived based on emissions measurement data found in the literature. Livestock PM emissions factors from

22 http://www.epa.gov/ttn/chief/ap42/ch13/final/c13s0204.pdf
23 USEPA, "Emissions from Animal Feeding Operations – Draft" (2001), OAQPS, RTP, NC, http://www.epa.gov/ttn/chief/ap42/ch09/draft/draftanimalfeed.pdf

the literature are applied to model farms, which represent different plausible configurations of farming activities and their associated emissions. Table 4 shows the PM emission factors derived from model farms for different agricultural sources.

Table 4. PM emisson factors for livestock sources

Livestock	Emission Factor (tons/animal-year)
Beef	0.0064
Veal	0.0
Dairy	0.0012
Swine	0.004
Broilers	0.0042
Turkeys	0.0094

Without a technical support document that describes how the non-ammonia livestock source emissions are calculated in the 2008 NEI, it's not clear if these emissions factors were used to estimate the county-level PM emissions contained in the inventory.

Emission factor information on PM emissions from fertilizer applications in the AP-42 and the 2008 NEI is incomplete. The AP-42 cites a draft document from 1999 that states explicitly that insufficient information exists to calculate PM emissions from fertilizer application.[24] This statement is consistent with the 2008 NEI, which does not include PM emissions for fertilizer application SCCs.

The AP-42 includes two final documents for estimating emissions from harvesting operations. The AP-42 guidance documents for cotton harvesting[25] and grain harvesting[26] include PM emissions factors from both activities. Given the lack of a technical support document on crop emissions for the 2008 NEI, it's not clear whether these emissions factors were applied or if another source of data was used to estimate PM emissions from the harvesting and tilling of crops in the 2008 NEI.

Emissions Processing

The road and fugitive dust source emissions were processed for the WestJumpAQMS with the Sparse Matrix Operator Kernel Emissions (SMOKE[27]) modeling system. Emissions are input as annual or average day totals by state, county, and SCC code. SMOKE applies temporal and spatial allocation profiles to distribute the county-level emissions to gridded, hourly emission estimates. Windblown dust emissions for the WestJumpAQMS were calculated using the WRAP WBD model and merged with the rest of the emission sources.

24 http://www.epa.gov/ttn/chief/ap42/ch09/draft/d09s0201.pdf
25 http://www.epa.gov/ttn/chief/ap42/ch09/final/c9s03-1.pdf
26 http://www.epa.gov/ttn/chief/ap42/ch09/final/c9s03-2.pdf
27 http://www.smoke-model.org/index.cfm

Spatial Allocation

Spatial allocation profiles have been updated using the best available population, roadway, and landuse geospatial datasets. Table 5 lists the surrogate assignments that were used to map road dust and fugitive dust emissions to the WestJumpAQMS modeling grids.

Table 5. Spatial surrogates used for modeling the fugitive dust sources in the 2008 NEIv2

Inventory Sectors	Surrogate	Surrogate Description	Surrogate Source
Paved Roads	240	Total Road Miles	US Census – TIGER (2010)
Unpaved Roads	130	Rural Population	US Census (2010)
Construction	140	Housing Change + Population	US Census (2010)
Mining and Quarrying	330	Strip Mines/Quarries	NLCD (1992)
Livestock	310	Total Agriculture	NLCD (1992)
Crop Production	310	Total Agriculture	NLCD (1992)

Details of the development and application of the spatial allocation profiles will be included in Technical Memorandum No. 13.

Temporal Allocation

EPA provided temporal allocation factors for use with the 2008 NEIv2 datasets. Details of the development and application of the temporal allocation profiles will be included in Technical Memorandum No. 13.

Chemical Speciation

Speciation profiles for the Carbon Bond version 6 (CB6) chemical mechanism are based on recent work by Environ to update the SPECIATE 4.3 database. Speciation profiles are assigned to inventory sources by a combination of FIPS code, SCC code, pollutant, and plant identification code. EPA updated the speciation profile assignments for use with the 2008 NEIv2. Table 6 lists the speciation profile assignments that were used to convert inventory fugitive dust $PM_{2.5}$ to CAMx PM mechanism species. Note that CAMx includes two OPM2.5 species that are treated identically in CAMx, one that is typically used for crustal material (FCRS) and the other for non-crustal material (FPRM). Given the uncertainties in the WBD emissions, they were mapped to the FCRS species and all other OPM2.5 emissions (including fugitive dust) were mapped to the FPRM species. This way the WBD emissions can be isolated in the CAMx model output if performance issues are found.

Table 6. PM speciation profiles for modeling fugitive dust sources in the 2008 NEIv2; percent splits by $PM_{2.5}$ species

Inventory Sector	Profile	Profile Description	FPRM	PEC	PNO3	POA	PSO4
Paved Roads	92053	Draft Paved Road Dust – Simplified	0.8693	0.0104	0.0004	0.1169	0.0030
Unpaved Roads	92088	Draft Unpaved Road Dust – Simplified	0.9300	0.0010	0.0013	0.0655	0.0023
Construction	92020	Draft Construction Dust – Simplified	0.9431	0.0000	0.0004	0.0554	0.0011
Mining and Quarrying	92073	Draft Sand & Gravel – Simplified	0.9935	0.0000	0.0005	0.0000	0.0060
Livestock – Dairy	92023	Draft Dairy Soil – Simplified	0.4292	0.0516	0.0926	0.3820	0.0446
Livestock – Other	92001	Draft Agricultural Soil – Simplified	0.9611	0.0002	0.0006	0.0370	0.0011
Crop Production	92001	Draft Agricultural Soil – Simplified	0.9611	0.0002	0.0006	0.0370	0.0011

Details of the development of chemical speciation profiles are included in Technical Memorandum #13.

Fugitive Dust Transport Factors

The emissions factors for fugitive dust sources consider the parameters and conditions that produce dust emissions for different processes, such as the mechanisms of soil disturbance and the moisture and silt content of the disturbed surface. Although some fugitive dust emissions are based off of wind speeds and surface roughness, they do not explicitly include the direct effects of vegetative cover on dust scavenging. Pace[28] originally suggested the concept of a transportable fraction as the amount of dust that is not captured by near source removal.

For the WestJumpAQMS we implemented fugitive dust correction factors that are derived from the Biogenic Emission Landuse Database version 3 (BELD3)[29]. Following the approach of Pouliot et al.[30] we adjusted the fugitive and road dust emissions as a post-processing step after the emissions data were output from SMOKE. We used transport factors gridded to each of the WestJumpAQMS modeling domains to reduce the dust emissions. The values of the transport factors associated with each BELD3 land cover category is available in Pouliot et al.[28] Figure 4 is a plot of the fugitive dust transport factors on each of the WestJumpAQMS modeling grids.

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28 Pace, T.G. "Methodology to Estimate the Transportable Fraction (TF) of Fugitive Dust Emissions for Regional and Urban Scale Air Quality Analyses", U.S. EPA, Research Triangle Park NC, August 2005. http://www.epa.gov/ttnchie1/emch/dustfractions/transportable_fraction_080305_rev.pdf

29 Vukovich, J. and T. Pierce (2002) "The Implementation of BEIS3 within the SMOKE Modeling Framework", In Proceedings of the 11th International Emissions Inventory Conference, Atlanta, Georgia, April 15-18, 2002. Available online: www.epa.gov/ttn/chief/conference/ei11/modeling/vukovich.pdf

30 Pouliot, G. et al. (2010) "Assessing the Anthropogenic Fugitive Dust Emission Inventory and Temporal Allocation Using an Updated Speciation of Particulate Matter", In Proceedings of the 19th International Inventory Conference, San Antonio, TX, September 27-30, 2010, http://www.epa.gov/ttn/chief/conference/ei19/session9/pouliot.pdf

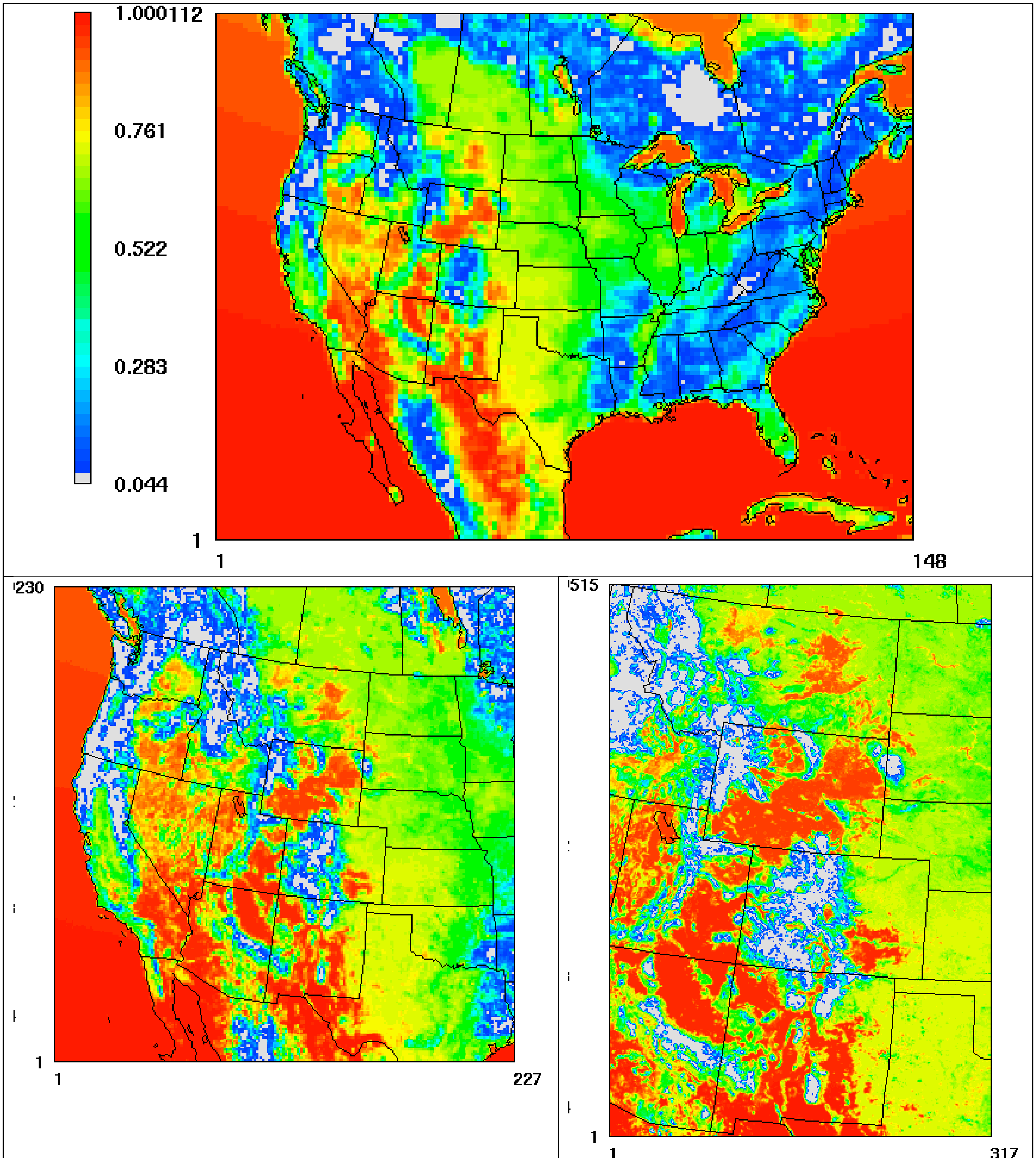


Figure 1. Dust transport factors on the WestJumpAQMS 36, 12, and 4 km modeling domains

Quality Assurance

Quality assurance (QA) will be performed following the emissions quality assurance protocol developed for the WRAP Regional Modeling Center (Adelman, 2004[31]). These procedures include systematic procedures for:

- Modeling QA – accuracy assurance and problem identification.
- System QA – software and data tracking.
- Documentation – tracking QA issues, recording the QA process and report writing.

An emissions QA checklist is developed that delineates each step of the QA process and allows a systematic approach to the QA process to assure critical steps are not overlooked. The completed QA checklists and templates include:

- Model configuration settings.
- Inventory file log.
- Ancillary input file log.
- Model execution log.

A series of QA products are produced that are compared to other studies and the expected outcomes:

- Spatial plots of emissions by source category.
- Annual time series plots of emissions for subregions.
- Diurnal time series plots.
- Daily vertical profile plots.

Dust Emissions Modeling Results

Table 7 shows state total $PM_{2.5}$ emissions for each for each of the major inventory source categories, including the fugitive dust sources from the 2008 NEI ("Dust") and the adjusted WBD model ("WBD"). Texas has the highest fugitive dust emissions (171,368 tons per year, TPY) that represents 15% of the total U.S. and is over twice that for the next highest state (Kansas with 77,675 TPY). Texas also has the highest WBD $PM_{2.5}$ emissions (85,509 TPY), followed by Kansas (64,378 TPY).

Fugitive dust and WBD $PM_{2.5}$ emissions represent 26% and 11%, respectively, of the total 2008 $PM_{2.5}$ emissions across the contiguous U.S. (Table 8). In general, WRAP and central U.S. states have a higher contribution of WBD emissions to their total $PM_{2.5}$ emissions than eastern states, with the exception of the high 2008 fire emissions states (e.g., California where fires contribute 58% of the $PM_{2.5}$ emissions).

Figure 2 displays the 2008 NEI fugitive dust emissions across the 36 km CONUS domain for a representative weekday from January, April, July and October 2008. The fugitive dust emissions across the 12 km WESTUS domain and January and July are shown in Figure 3. The dust emissions tend to be higher in the summer than winter. Annual 2008 windblown dust (WBD) coarse and fine PM emissions

31 http://www.epa.gov/ttnchie1/conference/ei13/qaqc/adelman_pres.pdf

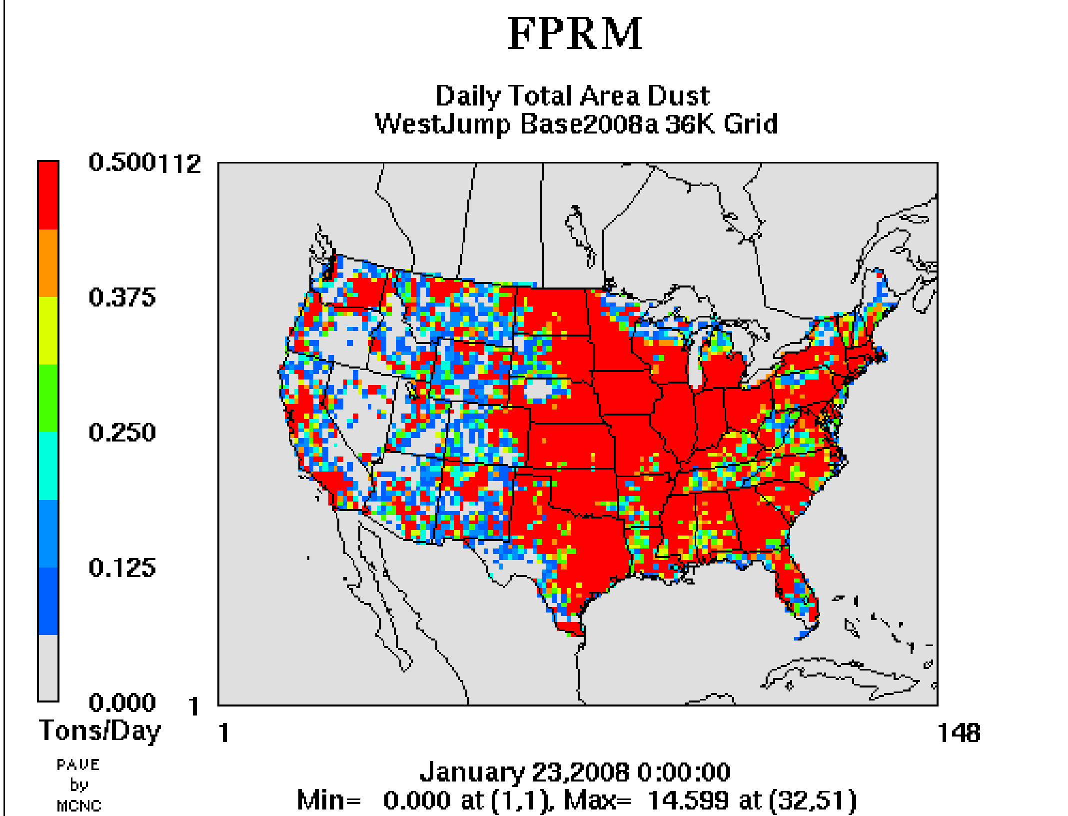
are shown in Figure 4 across the CONUS domain. Note that the resolution of the WBD emissions is as high as 4 km in the Inter-Mountain West domain and as low as 36 km in areas not covered by the 12 km WESTUS domain.

Table 7. Summary of 2008 $PM_{2.5}$ emissions (tons per year) by state and major source category (not shown are 38,019 TPY near-shore and 37,227 TPY off-shore commercial marine vessel and Mexico/Canada emissions).

State	Area	Area-O&G	Dust	Biogenic	Off-Road	On-Road	Fires	WBD	PT-O&G	PTCEM	PTNCEM	Total
Alabama	7,761	-	8,953	-	2,544	15,806	50,163	957	-	2,786	22,181	111,151
Arizona	16,114	-	26,124	-	3,311	8,756	8,238	9,307	-	1,904	3,730	77,483
Arkansas	7,214	-	23,607	-	2,474	5,416	27,885	5,397	-	1,236	6,452	79,682
California	83,888	7	39,371	-	14,681	18,437	261,920	12,133	-	965	22,741	454,144
Colorado	14,940	2,106	24,330	-	3,071	9,096	2,625	13,138	436	527	7,498	77,768
Connecticut	8,285	-	913	-	1,355	9,107	18	1	-	121	220	20,021
Delaware	1,143	-	716	-	455	2,265	80	11	-	1,875	1,080	7,626
District of Columbia	814	-	35	-	222	788	0	0	-	-	46	1,904
Florida	15,772	-	16,662	-	10,508	35,438	68,475	768	-	13,160	16,451	177,234
Georgia	22,019	-	17,096	-	4,864	29,351	47,301	562	-	5,999	6,567	133,760
Idaho	7,103	-	13,387	-	1,545	3,106	26,192	5,286	-	-	2,369	58,988
Illinois	27,875	-	64,780	-	8,397	18,873	1,918	8,083	-	5,474	12,037	147,437
Indiana	19,589	-	36,082	-	4,494	13,803	1,421	2,988	-	30,115	27,476	135,968
Iowa	7,787	-	51,972	-	5,025	6,166	979	27,674	-	5,657	5,796	111,055
Kansas	6,400	-	77,675	-	3,792	5,191	14,334	64,378	-	1,747	3,633	177,149
Kentucky	11,745	-	9,442	-	2,612	16,114	4,488	3,742	-	6,459	17,473	72,075
Louisiana	15,194	-	10,039	-	2,572	7,284	44,019	3,557	-	3,506	45,877	132,050
Maine	9,104	-	1,374	-	1,062	3,064	78	55	-	50	2,781	17,568
Maryland	10,694	-	3,773	-	2,447	8,389	550	137	-	5,945	2,674	34,609
Massachusetts	11,736	-	4,269	-	2,286	8,617	313	4	-	600	1,296	29,121
Michigan	36,601	-	21,668	-	6,539	17,931	820	1,628	-	1,602	13,401	100,191
Minnesota	24,606	-	47,934	-	6,025	10,909	1,971	10,661	-	3,470	12,909	118,484
Mississippi	10,035	-	13,082	-	1,917	6,410	25,544	3,597	-	1,007	7,053	68,644
Missouri	13,580	-	40,722	-	4,432	12,319	6,220	15,762	-	5,252	6,240	104,526
Montana	3,593	23	25,220	-	1,692	2,382	9,354	26,475	8	221	1,955	70,922
Nebraska	5,433	-	45,950	-	3,263	3,691	1,241	29,728	-	1,871	2,056	93,232
Nevada	3,760	-	20,186	-	1,700	3,142	1,273	17,051	-	360	3,082	50,555
New Hampshire	6,678	-	442	-	796	2,479	25	6	-	592	3,101	14,121
New Jersey	10,318	-	1,607	-	3,307	11,986	1,078	35	-	4,333	2,766	35,431
New Mexico	5,374	750	59,604	-	835	4,774	3,766	28,151	349	686	543	104,831
New York	35,271	-	10,198	-	7,154	22,203	684	904	-	1,867	4,423	82,706
North Carolina	21,750	-	8,537	-	4,954	15,132	31,244	664	-	16,969	8,712	107,962
North Dakota	1,808	-	44,139	-	3,199	1,777	2,577	15,784	-	306	2,275	71,865
Ohio	37,916	-	28,074	-	6,245	19,732	1,451	2,854	-	43,349	21,670	161,290
Oklahoma	9,666	397	52,850	-	2,596	7,516	13,316	26,462	-	3,328	5,665	121,796
Oregon	17,175	-	10,030	-	2,289	6,767	30,947	8,499	-	706	8,394	84,807
Pennsylvania	30,841	-	8,054	-	5,026	19,078	2,917	319	-	53,923	13,991	134,150
Rhode Island	2,367	-	304	-	331	1,329	59	1	-	5	128	4,524
South Carolina	8,718	-	7,207	-	2,414	8,408	18,740	466	-	14,524	5,619	66,095
South Dakota	1,957	-	26,458	-	2,295	1,987	1,163	34,242	-	229	655	68,985
Tennessee	21,053	-	8,628	-	3,323	11,796	6,951	2,434	-	5,284	9,938	69,408
Texas	26,077	4,842	171,368	-	14,531	32,677	41,533	85,509	872	11,599	29,328	418,337
Utah	5,220	664	15,122	-	1,436	4,435	1,815	10,810	42	883	3,133	43,560
Vermont	8,051	-	616	-	443	1,550	68	12	-	43	95	10,876
Virginia	19,633	-	4,374	-	3,771	12,847	14,930	578	-	1,618	7,250	65,000
Washington	20,579	-	16,042	-	3,638	9,883	10,463	4,520	-	459	3,962	69,545
West Virginia	7,771	-	1,186	-	873	3,958	3,915	66	-	25,969	4,288	48,025
Wisconsin	34,858	-	19,855	-	4,694	11,848	1,046	2,422	-	606	3,037	78,365
Wyoming	2,587	1,105	37,636	-	551	2,032	12,061	5,631	229	7,371	15,897	85,099
Tribal Data	137	-	-	-	-	-	-	-	-	5,659	949	6,744
Grand Total	738,591	9,894	1,177,689	-	177,987	496,045	808,173	493,451	1,935	302,214	410,891	4,616,870

Table 8. Percent contribution of source categories to $PM_{2.5}$ emissions by state.

State	Area	Area-O&G	Dust	Biogenic	Off-Road	On-Road	Fires	WBD	PT-O&G	PTCEM	PTNCEM
Alabama	7.0%	0.0%	8.1%	0.0%	2.3%	14.2%	45.1%	0.9%	0.0%	2.5%	20.0%
Arizona	20.8%	0.0%	33.7%	0.0%	4.3%	11.3%	10.6%	12.0%	0.0%	2.5%	4.8%
Arkansas	9.1%	0.0%	29.6%	0.0%	3.1%	6.8%	35.0%	6.8%	0.0%	1.6%	8.1%
California	18.5%	0.0%	8.7%	0.0%	3.2%	4.1%	57.7%	2.7%	0.0%	0.2%	5.0%
Colorado	19.2%	2.7%	31.3%	0.0%	3.9%	11.7%	3.4%	16.9%	0.6%	0.7%	9.6%
Connecticut	41.4%	0.0%	4.6%	0.0%	6.8%	45.5%	0.1%	0.0%	0.0%	0.6%	1.1%
Delaware	15.0%	0.0%	9.4%	0.0%	6.0%	29.7%	1.1%	0.1%	0.0%	24.6%	14.2%
District of Columbia	42.7%	0.0%	1.8%	0.0%	11.6%	41.4%	0.0%	0.0%	0.0%	0.0%	2.4%
Florida	8.9%	0.0%	9.4%	0.0%	5.9%	20.0%	38.6%	0.4%	0.0%	7.4%	9.3%
Georgia	16.5%	0.0%	12.8%	0.0%	3.6%	21.9%	35.4%	0.4%	0.0%	4.5%	4.9%
Idaho	12.0%	0.0%	22.7%	0.0%	2.6%	5.3%	44.4%	9.0%	0.0%	0.0%	4.0%
Illionis	18.9%	0.0%	43.9%	0.0%	5.7%	12.8%	1.3%	5.5%	0.0%	3.7%	8.2%
Indiana	14.4%	0.0%	26.5%	0.0%	3.3%	10.2%	1.0%	2.2%	0.0%	22.1%	20.2%
Iowa	7.0%	0.0%	46.8%	0.0%	4.5%	5.6%	0.9%	24.9%	0.0%	5.1%	5.2%
Kansas	3.6%	0.0%	43.8%	0.0%	2.1%	2.9%	8.1%	36.3%	0.0%	1.0%	2.1%
Kentucky	16.3%	0.0%	13.1%	0.0%	3.6%	22.4%	6.2%	5.2%	0.0%	9.0%	24.2%
Louisiana	11.5%	0.0%	7.6%	0.0%	1.9%	5.5%	33.3%	2.7%	0.0%	2.7%	34.7%
Maine	51.8%	0.0%	7.8%	0.0%	6.0%	17.4%	0.4%	0.3%	0.0%	0.3%	15.8%
Maryland	30.9%	0.0%	10.9%	0.0%	7.1%	24.2%	1.6%	0.4%	0.0%	17.2%	7.7%
Massachusetts	40.3%	0.0%	14.7%	0.0%	7.8%	29.6%	1.1%	0.0%	0.0%	2.1%	4.5%
Michigan	36.5%	0.0%	21.6%	0.0%	6.5%	17.9%	0.8%	1.6%	0.0%	1.6%	13.4%
Minnesota	20.8%	0.0%	40.5%	0.0%	5.1%	9.2%	1.7%	9.0%	0.0%	2.9%	10.9%
Mississippi	14.6%	0.0%	19.1%	0.0%	2.8%	9.3%	37.2%	5.2%	0.0%	1.5%	10.3%
Missouri	13.0%	0.0%	39.0%	0.0%	4.2%	11.8%	6.0%	15.1%	0.0%	5.0%	6.0%
Montana	5.1%	0.0%	35.6%	0.0%	2.4%	3.4%	13.2%	37.3%	0.0%	0.3%	2.8%
Nebraska	5.8%	0.0%	49.3%	0.0%	3.5%	4.0%	1.3%	31.9%	0.0%	2.0%	2.2%
Nevada	7.4%	0.0%	39.9%	0.0%	3.4%	6.2%	2.5%	33.7%	0.0%	0.7%	6.1%
New Hampshire	47.3%	0.0%	3.1%	0.0%	5.6%	17.6%	0.2%	0.0%	0.0%	4.2%	22.0%
New Jersey	29.1%	0.0%	4.5%	0.0%	9.3%	33.8%	3.0%	0.1%	0.0%	12.2%	7.8%
New Mexico	5.1%	0.7%	56.9%	0.0%	0.8%	4.6%	3.6%	26.9%	0.3%	0.7%	0.5%
New York	42.6%	0.0%	12.3%	0.0%	8.6%	26.8%	0.8%	1.1%	0.0%	2.3%	5.3%
North Carolina	20.1%	0.0%	7.9%	0.0%	4.6%	14.0%	28.9%	0.6%	0.0%	15.7%	8.1%
North Dakota	2.5%	0.0%	61.4%	0.0%	4.5%	2.5%	3.6%	22.0%	0.0%	0.4%	3.2%
Ohio	23.5%	0.0%	17.4%	0.0%	3.9%	12.2%	0.9%	1.8%	0.0%	26.9%	13.4%
Oklahoma	7.9%	0.3%	43.4%	0.0%	2.1%	6.2%	10.9%	21.7%	0.0%	2.7%	4.7%
Oregon	20.3%	0.0%	11.8%	0.0%	2.7%	8.0%	36.5%	10.0%	0.0%	0.8%	9.9%
Pennsylvania	23.0%	0.0%	6.0%	0.0%	3.7%	14.2%	2.2%	0.2%	0.0%	40.2%	10.4%
Rhode Island	52.3%	0.0%	6.7%	0.0%	7.3%	29.4%	1.3%	0.0%	0.0%	0.1%	2.8%
South Carolina	13.2%	0.0%	10.9%	0.0%	3.7%	12.7%	28.4%	0.7%	0.0%	22.0%	8.5%
South Dakota	2.8%	0.0%	38.4%	0.0%	3.3%	2.9%	1.7%	49.6%	0.0%	0.3%	0.9%
Tennessee	30.3%	0.0%	12.4%	0.0%	4.8%	17.0%	10.0%	3.5%	0.0%	7.6%	14.3%
Texas	6.2%	1.2%	41.0%	0.0%	3.5%	7.8%	9.9%	20.4%	0.2%	2.8%	7.0%
Utah	12.0%	1.5%	34.7%	0.0%	3.3%	10.2%	4.2%	24.8%	0.1%	2.0%	7.2%
Vermont	74.0%	0.0%	5.7%	0.0%	4.1%	14.3%	0.6%	0.1%	0.0%	0.4%	0.9%
Virginia	30.2%	0.0%	6.7%	0.0%	5.8%	19.8%	23.0%	0.9%	0.0%	2.5%	11.2%
Washington	29.6%	0.0%	23.1%	0.0%	5.2%	14.2%	15.0%	6.5%	0.0%	0.7%	5.7%
West Virginia	16.2%	0.0%	2.5%	0.0%	1.8%	8.2%	8.2%	0.1%	0.0%	54.1%	8.9%
Wisconsin	44.5%	0.0%	25.3%	0.0%	6.0%	15.1%	1.3%	3.1%	0.0%	0.8%	3.9%
Wyoming	3.0%	1.3%	44.2%	0.0%	0.6%	2.4%	14.2%	6.6%	0.3%	8.7%	18.7%
Tribal Data	2.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	83.9%	14.1%
Grand Total	16.0%	0.2%	25.5%	0.0%	3.9%	10.7%	17.5%	10.7%	0.0%	6.5%	8.9%



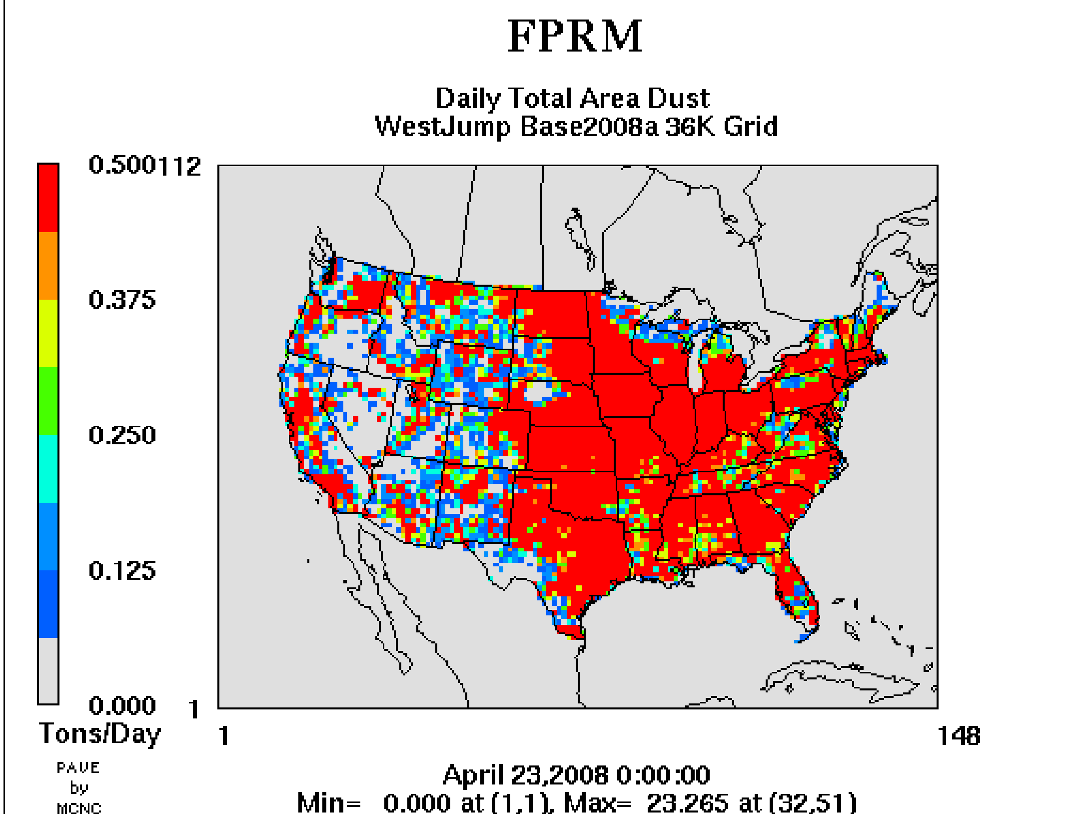
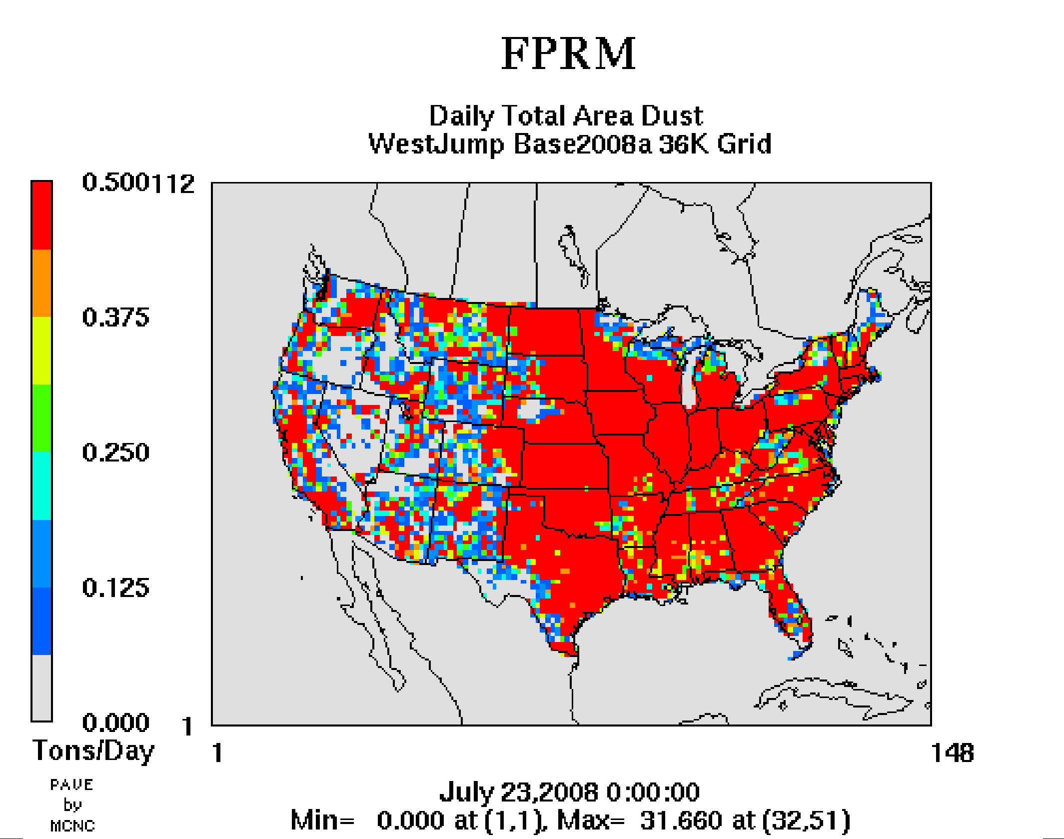


Figure 2a. Fugitive dust $PM_{2.5}$ emissions (tons per day) for 36 km CONUS domain from 2008 NEI for Wednesdays from January (top) and April (bottom) 2008.



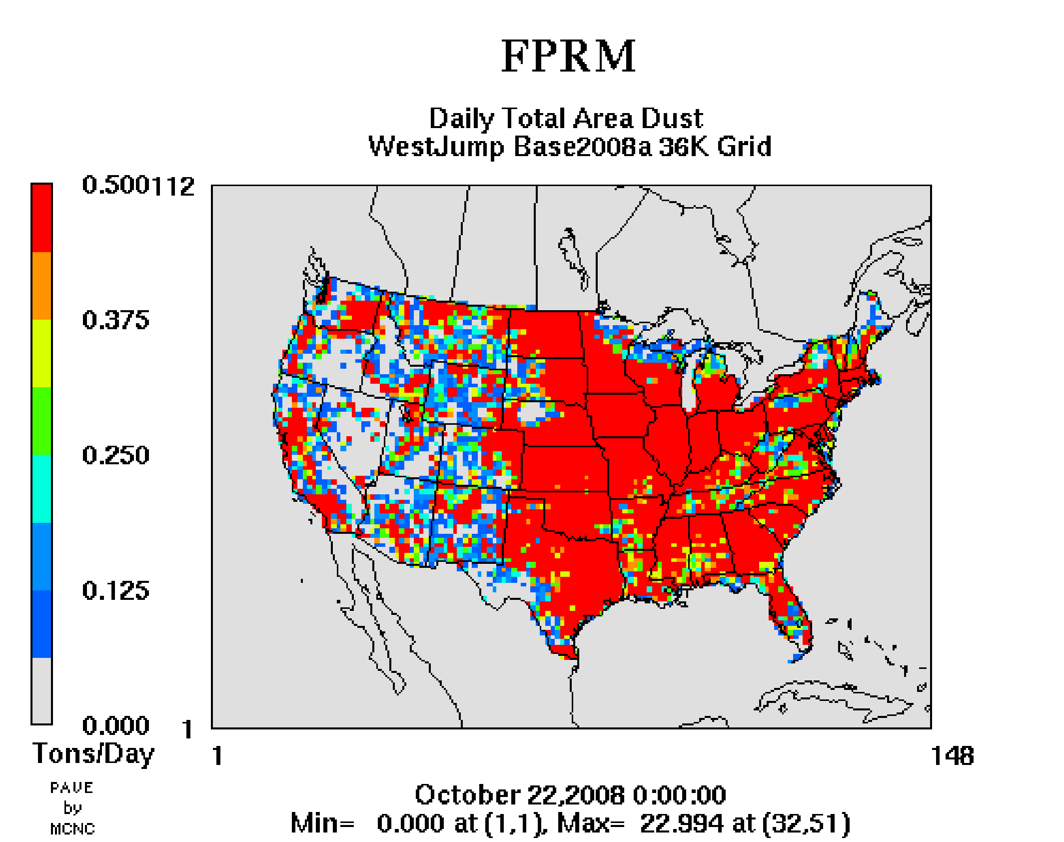
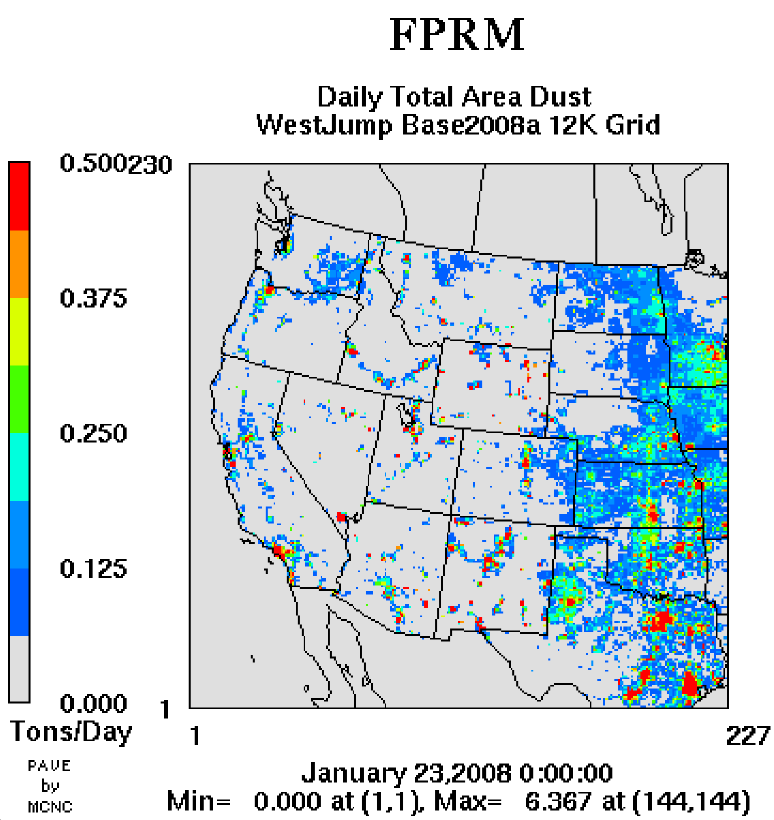


Figure 2b. Fugitive dust $PM_{2.5}$ emissions (tons per day) for 36 km CONUS domain from 2008 NEI for Wednesdays from July (top) and October (bottom) 2008.



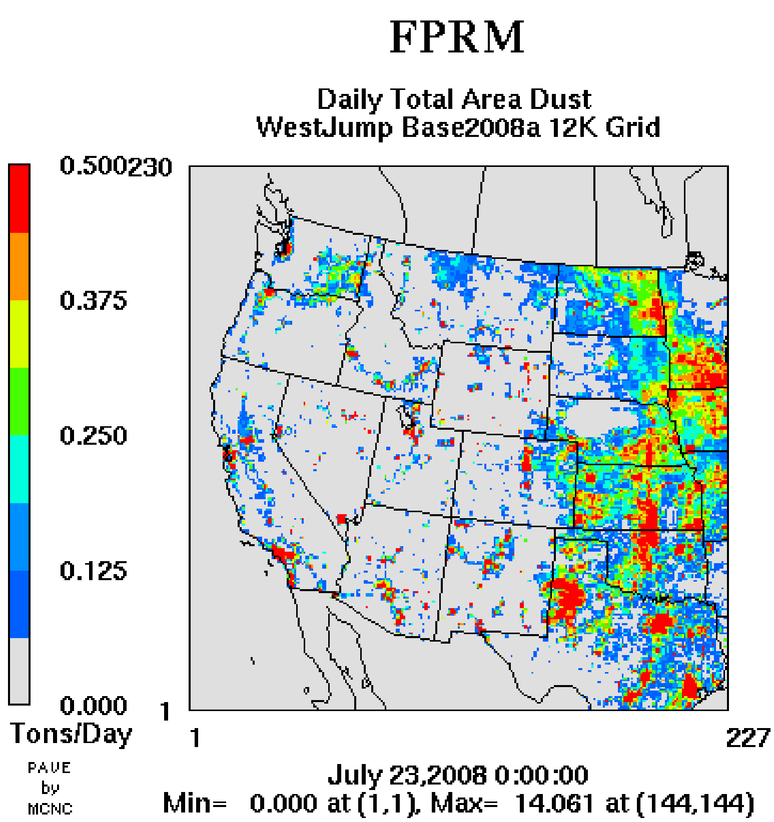


Figure 3. Fugitive dust $PM_{2.5}$ emissions (tons per day) for 12 km WESTUS domain from 2008 NEI for Wednesdays from January (top) and July (bottom) 2008.

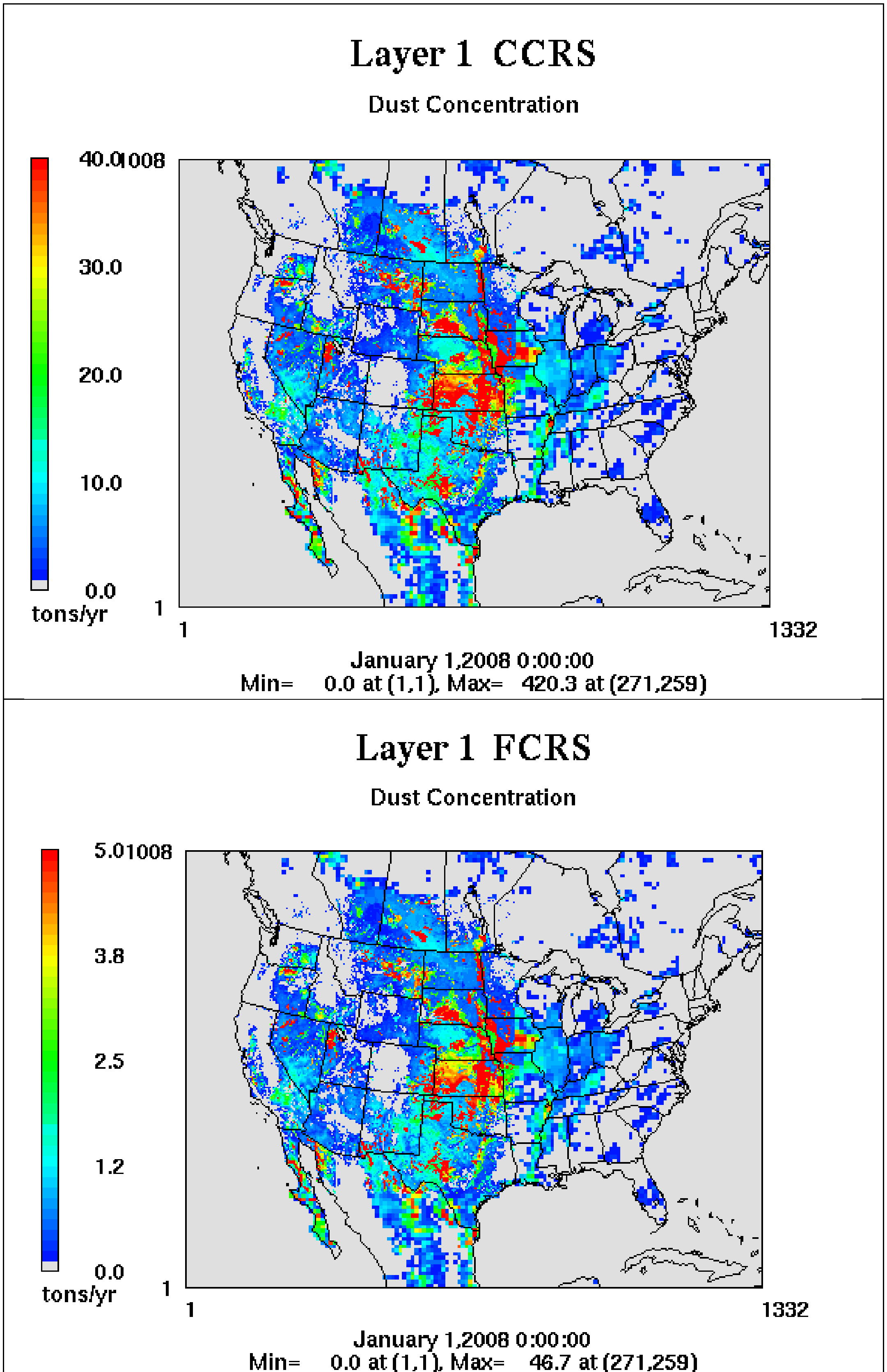


Figure 4. 2008 annual windblown dust (WBD) coarse mass (CCRS) and $PM_{2.5}$ (FCRS) emissions at 4 km resolution on the IMWD, 12 km on the WESTUS and 36 km on the CONUS domains.