CMAQ modeling of natural and anthropogenic dust aerosols over the Untied States

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1. Background

In order to accurately forecast $PM_{2.5}$ concentration, it is critical to understand the major aerosol sources and their uncertainties.

Anthropogenic fugitive dust is the largest emission source sector for fine and coarse particles ($PM_{2.5}$ and PM_{10}).

Anthropogenic ?

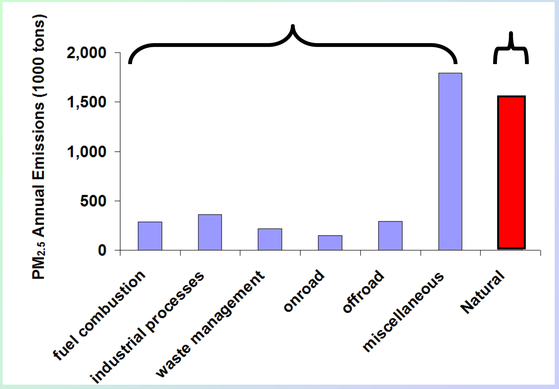

Figure 1. The US EPA National Emission Inventory estimates that anthropogenic dust emissions accounts for approximately 60% of the total primary $PM_{2.5}$ emissions.

Natural dust event occur frequently over the western United States, but their contribution to the US aerosol loading remains unknown.

2. Objectives

Central Science Question :

- How important is anthropogenic and natural dust emission for the US PM modeling?
- How well are these emission sources represented and modeld in the SMOKE-CMAQ system?

3. Advances in CMAQ dust aerosol modeling

Among other ongoing improvements, we present here the recent advances in dust aerosol modeling out of a NOAA-EPA fire and dust collaboration:

- The development of chemical profiles for natural dusts;
- Implementation of the dust emission scheme FENGSHA in CMAQ;
- Direct comparison of anthropogenic and natural dust predictions against individual aerosol composition measurements ;

CMAQ Modeling of Natural Dust Aerosols

Dust Emission Model Development

NOAA Air Resources Laboratory worked with EPA National Exposure Research Laboratory to have developed a windblown dust emission scheme for EPA's CMAQ model. This scheme, called FENGSHA, has been implemented in the CMAQ version 5.0 (Tong et al., JGR-Atmosphere, in revision).

Dust Emission Algorithm

The FENGSHA dust emission scheme is based on a modified Owen's equation:

Land use type, Soil type, Air density, Soil erodible potential

$$\text{Vertical flux} \rightarrow F = \sum_{i=1}^{M}\sum_{j=1}^{N} K \times A \times \frac{\rho}{g} \times S_i \times SEP \times u_* \times (u_*^2 - u_{*ti,j}^2) \quad (1)$$

Constants; Land use type; Friction velocity; Threshold friction velocity

Dust effects on surface PM_{10}

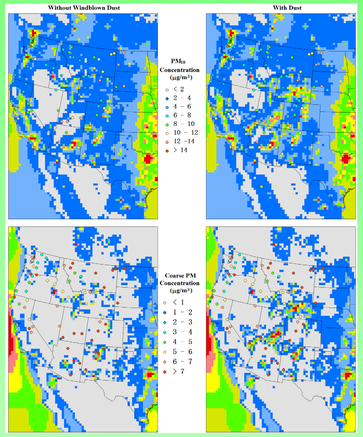

Fig. 2. Comparison of CMAQ and IMPROVE Coarse PM_{10} from April – June 2002.

Dust effects on aerosol light extinction

Aerosol light extinction is calculated using the IMPROVE reconstruction extinction method.

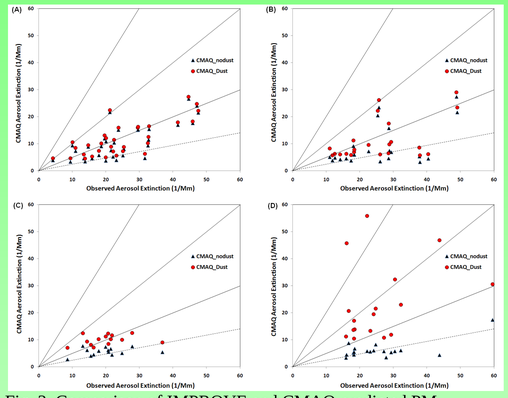

Fig. 3. Comparison of IMPROVE and CMAQ predicted PM_{10} concentrations at locations with varying dust influence. The data is grouped with dust contributing to modeled $PM_{2.5}$ concentrations by: A) 0.5 – 1.0; B) 1.0 – 2.0; C) 2.0 – 4.0; and D) larger than 4.0 μg/m^3.

Windblown Dust from Agricultural Land

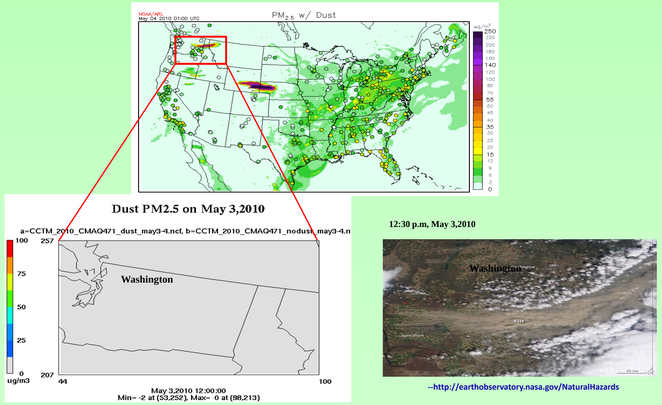

Fig. 4. CMAQ simulated and MODIS detected dust storms from cropland over the Pacific Northwest

Dust Chemical Composition

Dust identification approach

To further split dust into elements, we proposed a new approach to identify local dust events relying on aerosol mass and composition from general-purposed aerosol measurement. The IMPROVE network is used here. From the identified dust records, a chemical profile is compiled.

- High PM_{10}, $PM_{2.5}$ concentrations; } → Distinguish Dust
- High crustal elements: Al, Si, Ca, Fe and K;
- Low $PM_{2.5}/PM_{10}$ ratio; <0.35 Local Dust; >=0.35 Transported Dust/Fires
- Low anthropogenic pollutants: } Distinguish Dust from Man-made Pollution
- As, Zn, Pb, Cu, OC, EC and Nitrate;
- Low Enrichment Factor (EF): As, Zn,Pb, Cu.

A total of 129 local dust records found at 29 locations (2000 to 2007).

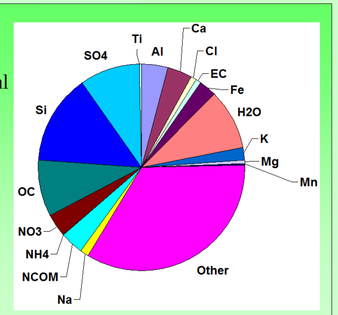

Fig. 5. Chemical profile of natural dust aerosols

Anthropogenic Dust Aerosols

Sources of anthropogenic dust emissions

Anthropogenic $PM_{2.5}$ emissions are estimated to be 1.84 Tg in the United States (www.epa.gov/ttn/chief/). These emissions are contributed by six major types: unpaved road, agricultural operation, construction, paved road, mining and animal activities (Figure 1).

Contribution to $PM_{2.5}$ concentration

Anthropogenic dust is predicted to exert dominant impacts on surface aerosol concentrations over the central and western U.S.

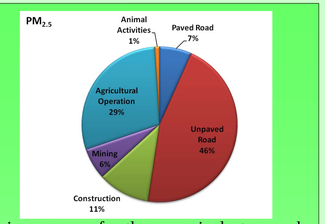

Fig. 6. Major sources of anthropogenic dust aerosols

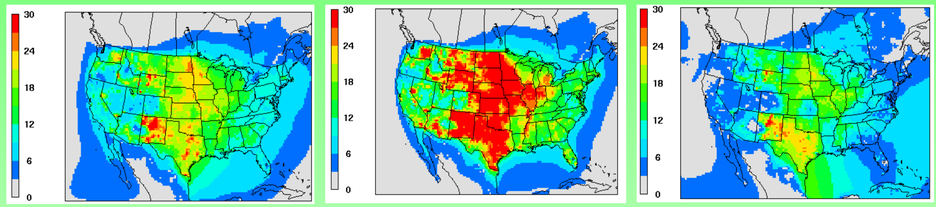

Fig. 7. CMAQ simulated annual contribution (%) of anthropogenic dust to PM2.5, PM10 and Particulate OC concentrations

Evaluation and Improvement

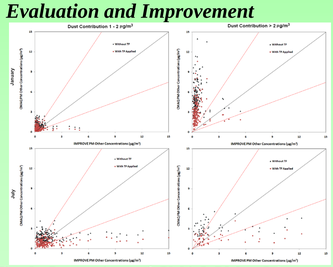

Fig. 8. Comparison of CMAQ $PM_{2.5}$ Other with IMPROVE measurements in January and July 2002. The largest biases are found at sites with high dust contribution in wintertime.

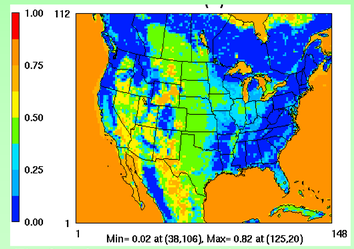

Fig. 9. A dynamic transportable fraction designed to adjust the raw fugitive dust emissions.

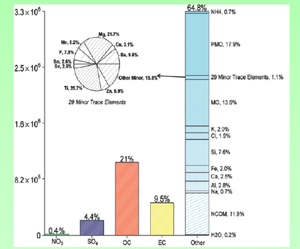

Fig. 10. Further chemical speciation of fugitive dust aerosols to allow CMAQ to simulate individual elements. This has been implemented in CMAQ 5.0.

Conclusion

- A physical-based dust emission algorithm FENGSHA has been developed and implemented in CMAQ 5.0;
- Anthropogenic dust is the largest sectors of known PM2.5 sources. Large uncertainties remain in the emission inventory that has not been updated for decades..

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