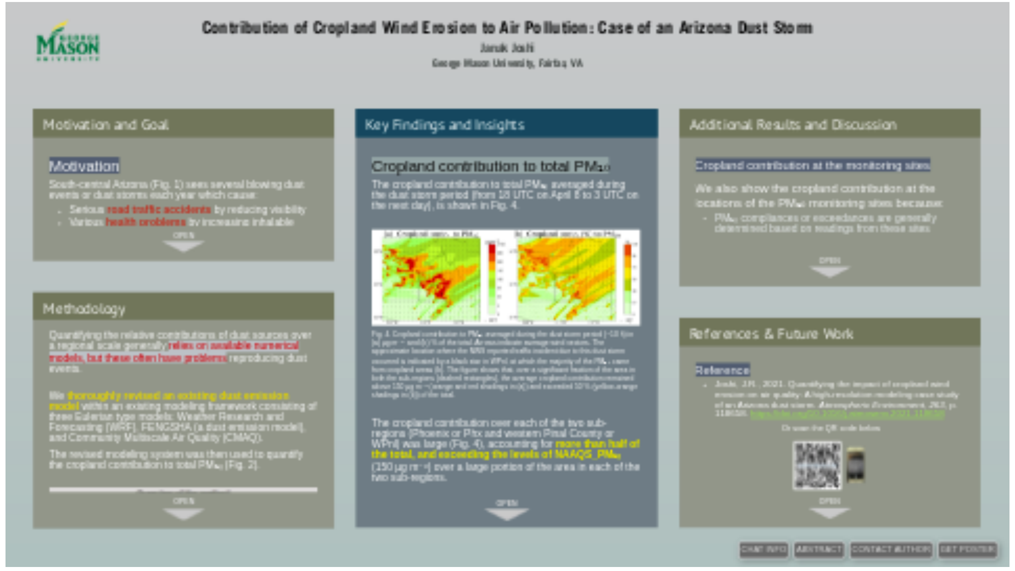
Contribution of Cropland Wind Erosion to Air Pollution: Case of an Arizona Dust Storm



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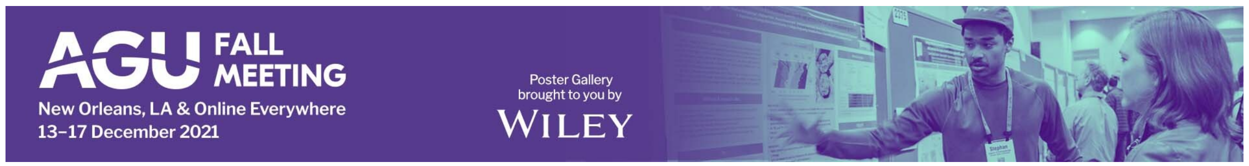


MOTIVATION AND GOAL

Motivation

South-central Arizona (Fig. 1) sees several blowing dust events or dust storms each year which cause:

- Serious **road traffic accidents** by reducing visibility
- Various **health problems** by increasing inhalable particle pollution in the air

Dust storm produces high levels of concentration of particulate matter having particles with diameters of less than 10 µm (PM_{10}). Such particles are inhalable and cause air pollution, a variety of health issues, and visibility reductions.

The United States Environmental Protection Agency (EPA) has established the National Ambient Air Quality Standards (NAAQS) to regulate particulate matter pollution due to PM_{10} (NAAQS_PM_{10}), which is not to exceed 150 µg m^{-3} averaged over 24 h. However, some areas in this region (Fig. 1) have failed to comply with such standards (part of the reason being windblown dust) and are, therefore, under the EPA's **PM_{10} nonattainment** classification.

Previous studies show that the main dust sources over this region are wind erosion from both natural desert land (e.g., shrub or barren land) and anthropogenically maintained land uses such as farmland or cropland (Fig. 1).

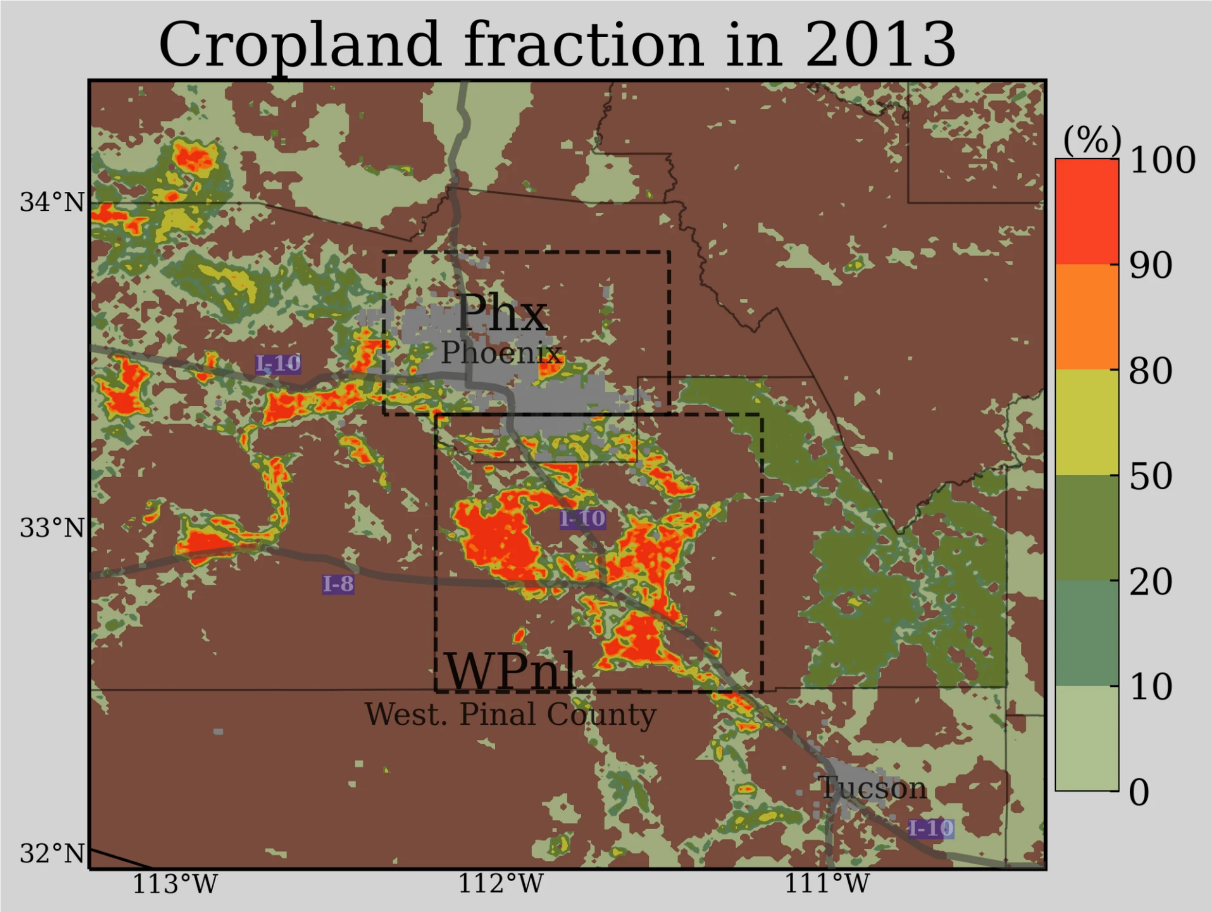
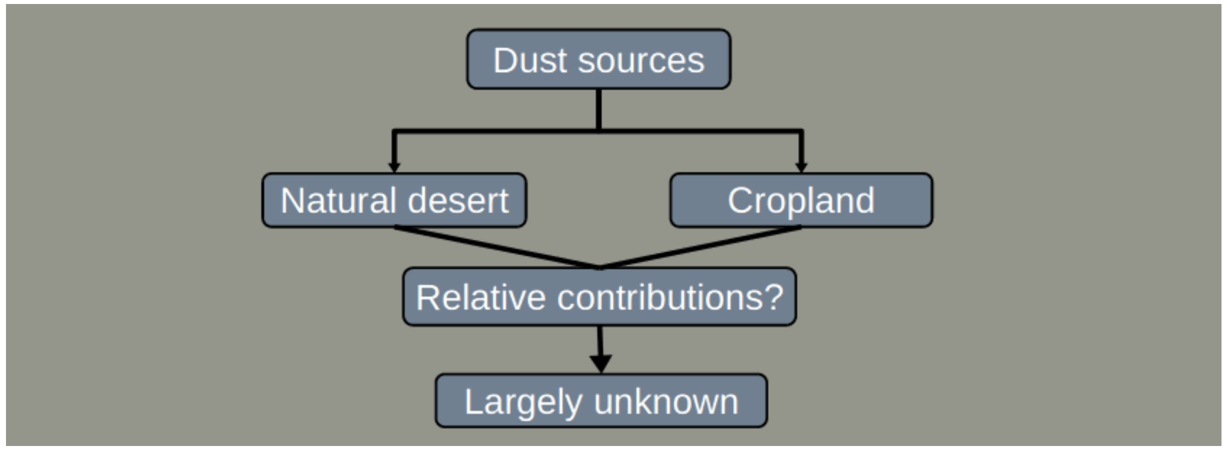


Fig. 1. Cropland fraction over south-central Arizona (our study domain). Dominantly urban land use (Phoenix and Tucson) is shown in light grey, and interstate highways passing through the region (I-10 and I-8) are labelled. The two sub-regions of interest are indicated by the dashed rectangles, which are Phoenix (Phx) and western Pinal County (WPnl). These sub-regions have their significant areas under the EPA's list of PM_{10} nonattainment, for which windblown dust is considered a significant contributor. The stretch of I-10 between Tucson and Phoenix, especially within WPnl and Phx, has a maximum in the records of dust-related traffic accidents over the region. The remaining land cover (tanned background) is mostly desert shrubland. Thus, a significant fraction of land use within and around these dust-prone sub-regions is cropland, whose contribution to air pollution during dust events remains largely unknown.

Unfortunately, **research is lacking** in quantifying the relative contributions of the two kinds of dust sources to air pollution during high wind events or dust storms (schematic below). Such quantification is required to design effective mitigation strategies to reduce hazards from windblown dust.



Schematic illustration indicating a need for dust source attribution studies

Although desert is generally considered the main dust source, cropland can be a significant dust source, especially when: unplanted, unirrigated, devoid of vegetation cover, or fallow. We test this hypothesis in this research.

Our Goal

- Present a methodology for source attribution of windblown dust during dust events
- Present results from a detailed case study of a dust storm quantifying the cropland contribution to total PM_{10} in south-central Arizona

PM_{10} causes air pollution and includes (breathable) particles less than 10 μm in diameter (average human hair is 70 μm in diameter)

METHODOLOGY

Quantifying the relative contributions of dust sources over a regional scale generally relies on available numerical models, but these often have problems reproducing dust events.

We **thoroughly revised an existing dust emission model** within an existing modeling framework consisting of three Eulerian type models: Weather Research and Forecasting (WRF), FENGSHA (a dust emission model), and Community Multiscale Air Quality (CMAQ).

The revised modeling system was then used to quantify the cropland contribution to total PM_{10} (Fig. 2).

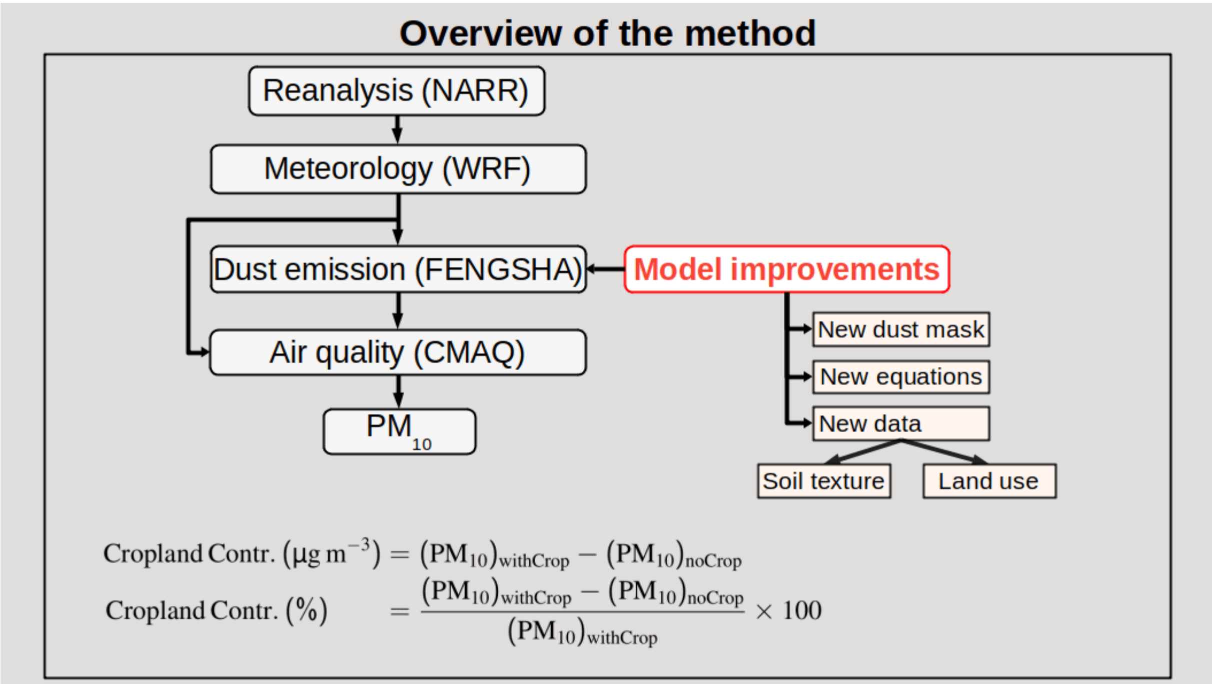


Fig. 2. An overview of the WRF-FENGSHA-CMAQ modeling system used in this study. Meteorology was first prepared by using the WRF model forced with data from the North American Regional Reanalysis (NARR). Thus produced meteorology was used to generate dust emissions using the dust model FENGSHA (offline), in which we incorporated important improvements (including new data and equations). Dust generated from FENGSHA and meteorology from WRF were then used to carry out air quality simulations using the CMAQ model, to produce dust-related output variables such as PM_{10}. Finally, the cropland contribution to PM_{10} was estimated using the equations shown at the bottom, in which the suffixes withCrop and noCrop indicate the model simulated values from two different experiments which were identical to each other in all respects except that one included dust from cropland (withCrop) and one did not include (noCrop). For details, see Joshi, 2021.

Major **improvements** we implemented in the dust model included introducing a new dust source mask based on vegetation cover, a new expression for sandblasting efficiency, and the incorporation of new data on land use and soil texture. Details are provided in Joshi, 2021.

Case study of a dust storm

We apply our method to simulate the case of a hazardous dust storm that occurred on 8–9 April 2013 over south-central Arizona (Fig. 3).

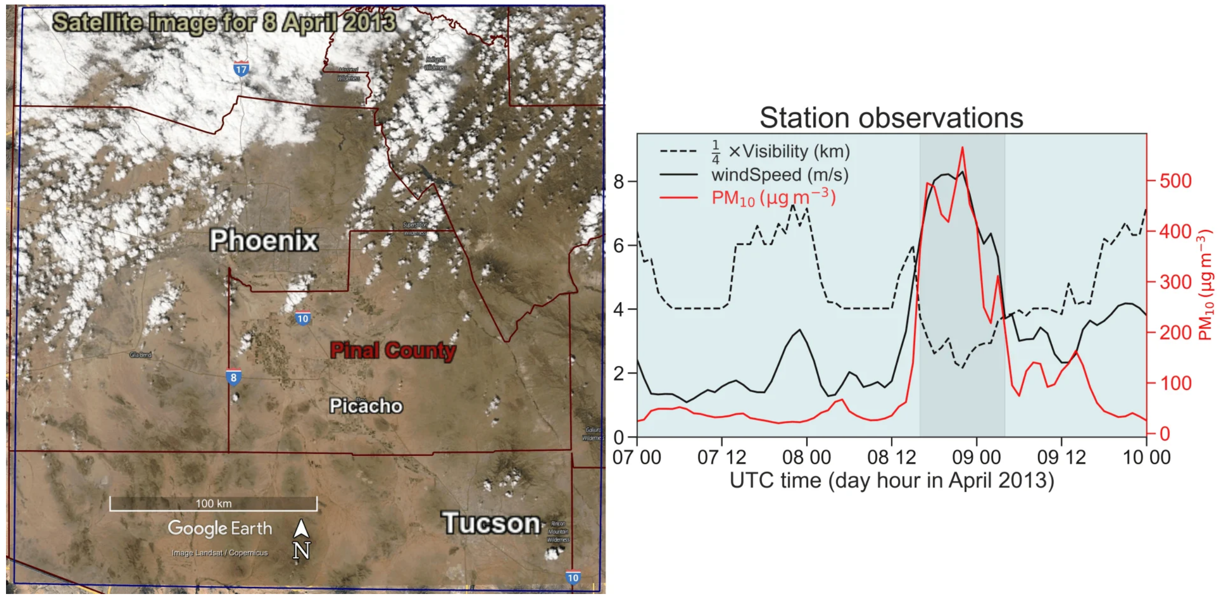


Fig. 3. (left) Satellite (MODIS Aqua) view of south-central Arizona on 8 April 2013 (around 21 UTC). The extent of the study area is indicated by the blue outline. Dust haze can be barely seen over Phoenix and neighboring areas. (right) station observations of near-surface wind speed, one-fourth of visibility, and PM_{10}, averaged over the study area. High levels of PM_{10} accompanied by high wind speed and reduced visibility (gray shaded region around 09 00 on the right) are the characteristics of a dust storm. The event lasted relatively long (more than 10 h), and PM_{10} values well exceeded NAAQS_PM_{10}, indicating that the event raised concerns for air quality. This dust storm caused a traffic incident near Picacho (reported by the national weather service or NWS).

This case of a dust storm was chosen for our initial study, especially because it was a springtime dust event (spring is when most dust activities occur over this region), large in spatial and temporal extents (more deleterious for health issues), and caused regional road traffic incidents involving minor injuries.

Because the dust emission process is highly sensitive to meteorology (e.g., surface wind speed) and ground surface conditions (soil, land use, vegetation cover, etc.), we employed our modeling at a **very high resolution of 1 km for the complex terrain domain** in south-central Arizona (details in Joshi, 2021).

The model evaluations (Joshi, 2021) included ground observations from the EPA's air quality system (AQS) PM_{10} monitoring sites, dual-pol radar observations, and satellite observations of dust optical depth and vertical structure of aerosol subtypes. The evaluations indicated the **simulations were reasonably well, giving us more confidence** in the dust source contribution quantification results.

KEY FINDINGS AND INSIGHTS

Cropland contribution to total PM_{10}

The cropland contribution to total PM_{10} averaged during the dust storm period (from 18 UTC on April 8 to 3 UTC on the next day), is shown in Fig. 4.

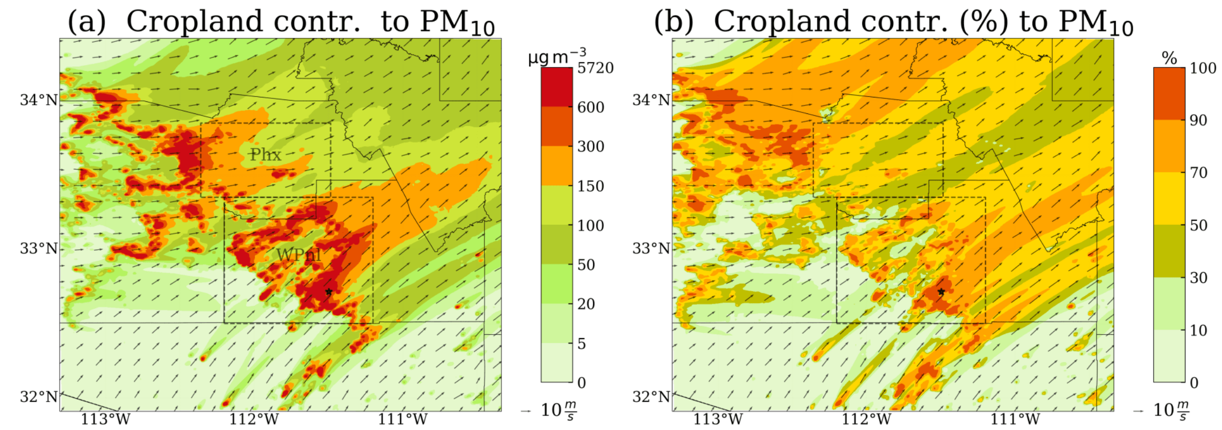


Fig. 4. Cropland contribution to PM_{10} averaged during the dust storm period (~10 h) in (a) μg m^{-3} and (b) % of the total. Arrows indicate average wind vectors. The approximate location where the NWS reported traffic incident due to this dust storm occurred is indicated by a black star in WPnl, at which the majority of the PM_{10} came from cropland areas (b). The figure shows that, over a significant fraction of the area in both the sub-regions (dashed rectangles), the average cropland contribution remained above 150 μg m^{-3} (orange and red shadings in (a)) and exceeded 50 % (yellow-orange shadings in (b)) of the total.

The cropland contribution over each of the two sub-regions (Phoenix or Phx and western Pinal County or WPnl) was large (Fig. 4), accounting for **more than half of the total, and exceeding the levels of NAAQS_PM_{10}** (150 μg m^{-3}) over a large portion of the area in each of the two sub-regions.

The NWS-reported **road traffic incident** (black star in Fig. 4 in WPnl) was **most likely due to cropland dust**.

Combining Phoenix (Phx) and western Pinal County (WPnl), the contribution over 54 % of the area exceeded the levels of NAAQS_PM_{10} (orange shadings on the right panel in Fig. 5).

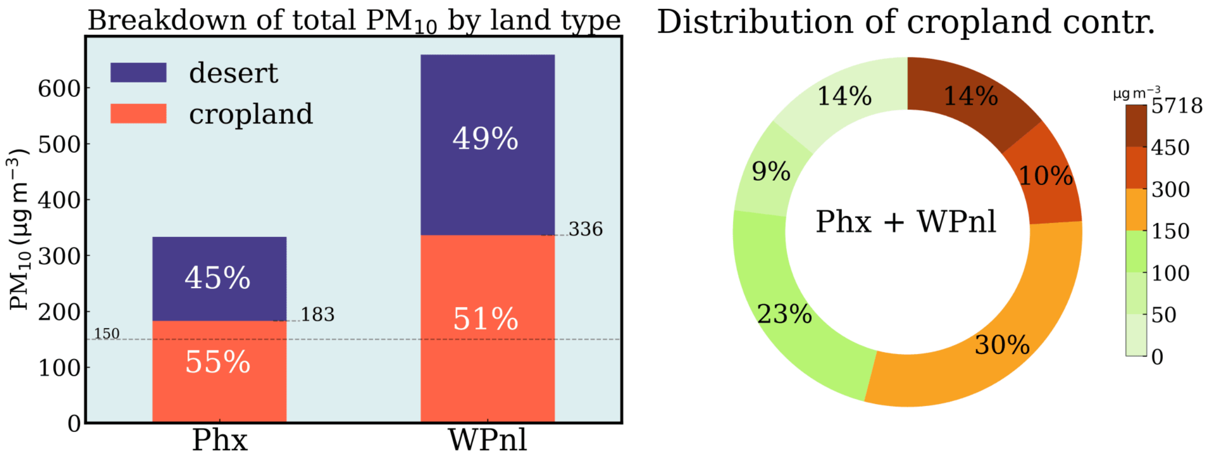


Fig. 5 (left) Breakdown of the total PM_{10} (averaged during the dust storm period) into dust sources, and (right) the areal distribution (combined over Phx and WPnl) of the average cropland contribution. On the left, numbers printed in % indicate the fraction of total PM_{10} contributed by each kind of dust source. Thus, cropland contribution to PM_{10} remained above 183 µg m⁻³ and accounted for little over half of the total, over both sub-regions.

Key findings

- **Contrary to the general belief** that desert is the main dust source, we found that, **cropland contributed more than half of the total PM_{10}** (exceeding the levels of ambient air quality standards or NAAQS) over Phoenix and western Pinal County, during the hazardous dust storm
- Therefore, air quality modeling over dryland regions **should not ignore cropland** as an important (dynamic) dust source
- We quantified, probably for the first time (at least for this region) the contribution of cropland dust to air pollution **over a regional scale during a dust storm**

Dust source attribution studies like ours will prove useful **to develop effective mitigation strategies**, in order to reduce dust-related hazards on public health and highway safety over this region or dryland regions, in general.

Such studies are more important in view of the projected **regional water reductions** (caused by climate change) for this region.

ADDITIONAL RESULTS AND DISCUSSION

Cropland contribution at the monitoring sites

We also show the cropland contribution at the locations of the PM_{10} monitoring sites because:

- PM_{10} compliances or exceedances are generally determined based on readings from these sites

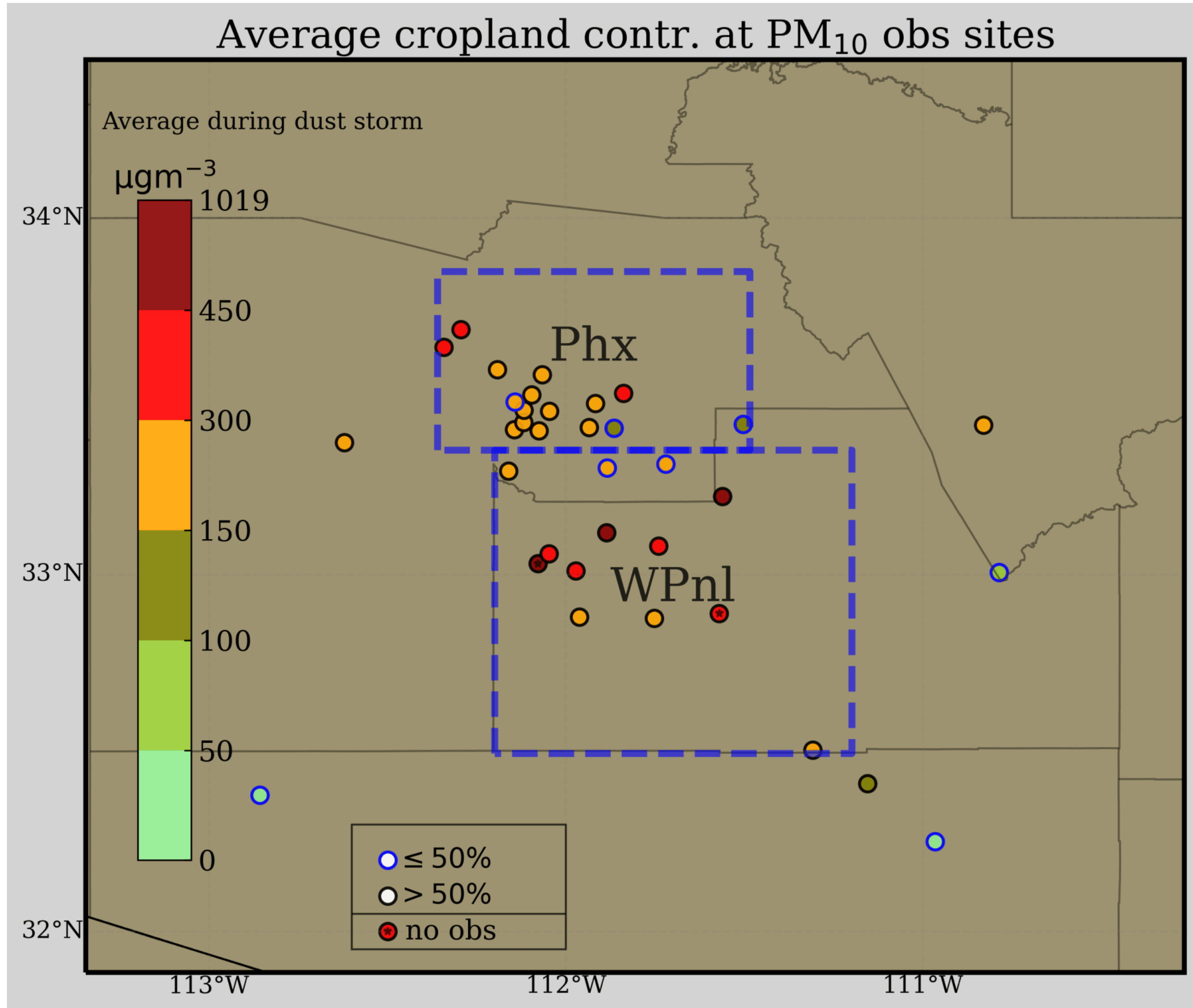


Fig. 6. Average (during the dust storm period) cropland contribution to total PM_{10} at the locations of the EPA's AQS PM_{10} monitoring sites. The average contributions exceeding the levels of the NAAQS for PM_{10} (150 µg m⁻³) are indicated by orange or red shadings and those below this level by greenish shades. The contributions exceeding and not exceeding 50 % of the total are indicated by circles with black and blue edges, respectively. Sites missing observations during the dust storm period are indicated by a black star inside their circles. It can be seen that at most of the sites in both sub-regions (blue dashed rectangles), the cropland contribution exceeded the NAAQS levels and was more than half of the total.

Over Phoenix (Phx), the cropland contribution exceeded:

- 150 µg m^{-3} at most of the sites
- 50 % of the total at most of the sites

Over western Pinal County (WPnl), the cropland contribution exceeded:

- 150 µg m^{-3} at all sites
- 50 % of the total at most of the sites

Because the average (over ~ 10 h) cropland contribution to total PM_{10} at most of the sites over both Phoenix and western Pinal County well exceeded the NAAQS_PM_{10} level of 150 µg m^{-3}, **the windblown dust from cropland, especially during high wind events, could be a significant contributor to violations of the EPA's air quality standards for PM_{10}** over these regions.

How was the time evolution of the contribution?

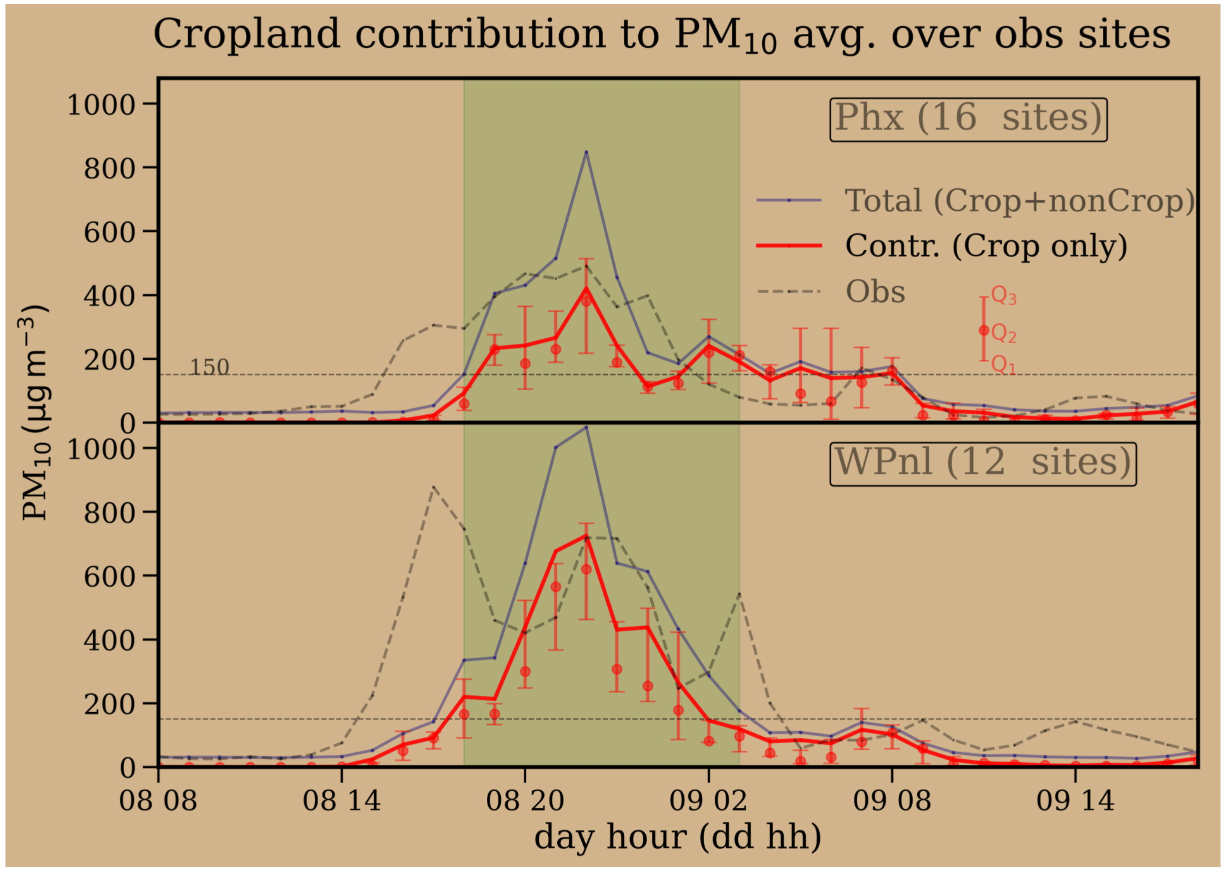


Fig. 7. Time series of cropland contribution (red curves) to total PM_{10} averaged over the PM_{10} observation sites (locations shown in Fig. 6) in the two sub-regions (Phx and WPnl). Error bars indicate the three quartile values (computed across observation sites): Q_1 (or 25th percentile), Q_2 (or 50th percentile or median), and Q_3 (or 75th percentile). Dashed horizontal lines indicate 150 µg m^{-3}. It is seen that the cropland contribution during the dust storm period (shaded in green) over both sub-regions mostly exceeded 150 µg m^{-3}. Even the 25th percentile remained generally high. To facilitate interpretations, the total simulated PM_{10} is shown by a thin blue curve and observations by a grey dashed curve.

Phx		WPnl	
µg m^{-3}	%	µg m^{-3}	%
218	59	360	66

Table 1. Average cropland contribution to total PM_{10} (in terms of concentration units or µg m^{-3} and % of the total) averaged during the dust storm period over the two sub-regions. Contributions **exceeded 59 %**, indicating that the agricultural land could be a major dust source during extreme wind events over these sub-regions.

The cropland contribution to PM_{10} across the monitoring sites in Phoenix and western Pinal County, during the dust storm period (Fig. 7), generally remained high (median values generally exceeding the levels of the NAAQS for PM_{10}). The average contributions (Table 1) exceeded 218 µg m^{-3} and accounted for more than 59 % of the total.

Thus, agricultural land or **cropland could be a strong source of windblown dust** over these areas **during high wind events**, potentially contributing to the **PM_{10} nonattainment** over these regions.

Such contributions **may worsen in the future** under the regional water shortages caused by climate change, **inviting more studies** on this topic.

REFERENCES & FUTURE WORK

Reference

- Joshi, J.R., 2021. Quantifying the impact of cropland wind erosion on air quality: A high-resolution modeling case study of an Arizona dust storm. *Atmospheric Environment*, *263*, p. 118658. https://doi.org/10.1016/j.atmosenv.2021.118658 (https://doi.org/10.1016/j.atmosenv.2021.118658)

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Future work

- Estimate the climatology of cropland contribution to air pollution
- Explore short-range predictability of dust storms

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ABSTRACT

Being in an arid zone that is frequently submitted to high winds, south-central Arizona regularly gets impacted by several blowing dust events or dust storms every year. Major consequences of these events are visibility impairment and ensuing road traffic accidents, and a variety of health issues induced by inhalation of polluted air loaded with fine particulate matter produced by wind erosion. Despite such problems, and thus a need for guidance on mitigation efforts, studies dealing with dust source attribution for the region are largely missing. Furthermore, existing dust models exhibit large uncertainties and deficiencies in simulating dust events, rendering them of limited use in attribution studies or early warning systems. Therefore, to address some of these model issues, we have developed a high-resolution (1 km) dust modeling system by building upon an existing modeling framework consisting of Weather Research and Forecasting (WRF), FENGSHA (a dust emission model), and Community Multiscale Air Quality (CMAQ) models. In addition to incorporating new representations in the dust emission scheme, including roughness correction factor, sandblasting efficiency, and dust source mask, we implemented, in the dust model, up-to-date and very high-resolution data on land use, soil texture, and vegetation index. We used the revised dust modeling system to simulate a springtime dust storm (08–09 April 2013) of relatively long duration that caused a regional traffic incident involving minor injuries. The model simulations compared reasonably well against observations of concentration of particulate matter with a diameter of 10 µm and smaller (PM_{10}) and satellite-derived dust optical depth and vertical profile of aerosol subtypes.

Interestingly, simulation results revealed that the anthropogenic (cropland) dust sources contributed more than half (~53 % or 260 $\mu g/m^3$) of total PM_{10}, during the dust storm, over the region including Phoenix and western Pinal County. Contrary to the conventional wisdom that desert is the main dust source, our findings for this region challenge such belief and suggest that the regional air quality modeling over dryland regions should emphasize an improved representation of dust from agricultural lands as well, especially during high wind episodes. Such representations have the potential to inform decision-making in order to reduce windblown dust-related hazards on public health and safety.