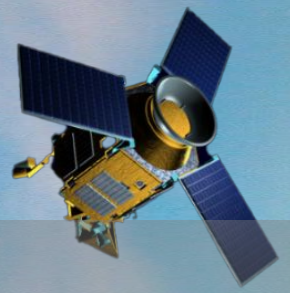
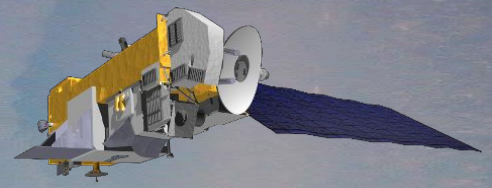
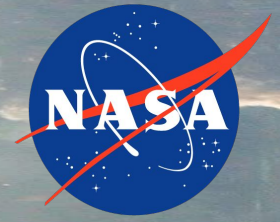




Tracking ambient air pollution from space: regional and global perspectives

Jing Wei[1], Zhanqing Li[1], & Jun Wang[2]

1. ESSIC, University of Maryland, College Park; 2. University of Iowa

Collaborators: Shobha Kondragunta, Susan Anenberg, Alexei Lyapustin, Xiong Liu, et al.



THE LANCET
Planetary Health

ARTICLES | VOLUME 7, ISSUE 12, E963-E975, DECEMBER 2023

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Long-term mortality burden trends attributed to black carbon and $PM_{2.5}$ from wildfire emissions across the continental USA from 2000 to 2020: a deep learning modelling study

Jing Wei, PhD • Prof Jun Wang, PhD • Prof Zhanqing Li, PhD • Shobha Kondragunta, PhD • Prof Susan Anenberg, PhD • Prof Yi Wang, PhD • Huanxin Zhang, PhD • David Diner, PhD • Jenny Hand, PhD • Alexei Lyapustin, PhD • Ralph Kahn, PhD • Peter Colarco, PhD • Arlindo da Silva, PhD • Prof Charles Ichoku, PhD •

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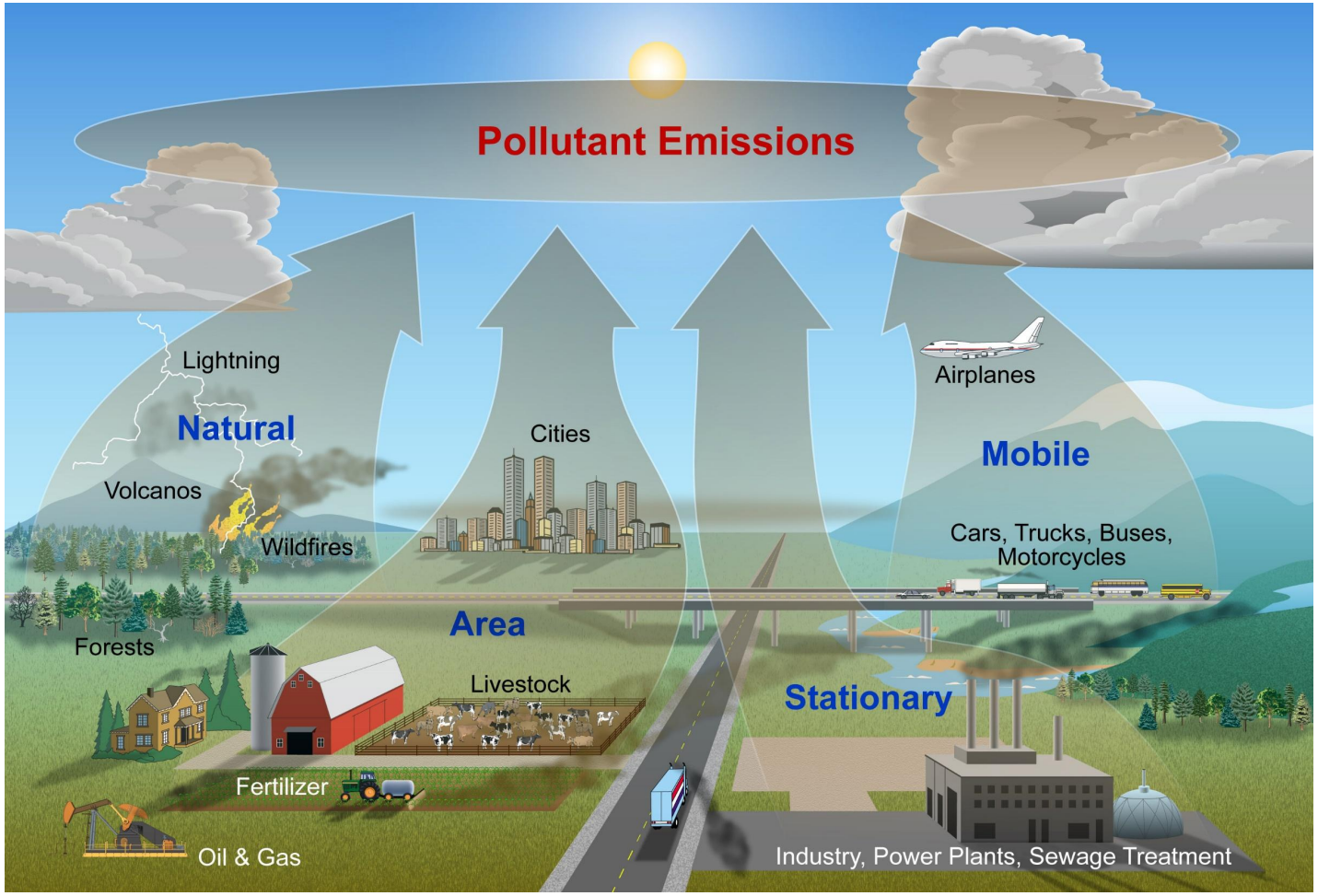
Open Access • Published: December, 2023 • DOI: https://doi.org/10.1016/S2542-5196(23)00235-8 •

Particulate Matter and Composition



- $PM_{2.5}$ is the **largest** environmental risk factor impacting both environment and health, but the sources are complex which make estimation highly **challenging**.
- $PM_{2.5}$ composition has strong and diverse impacts, especially for its **highly toxic BC** component. These effects are not well understood for **limited** surface observations and **uncertainties** in chemical model simulations.

Background (US air quality)

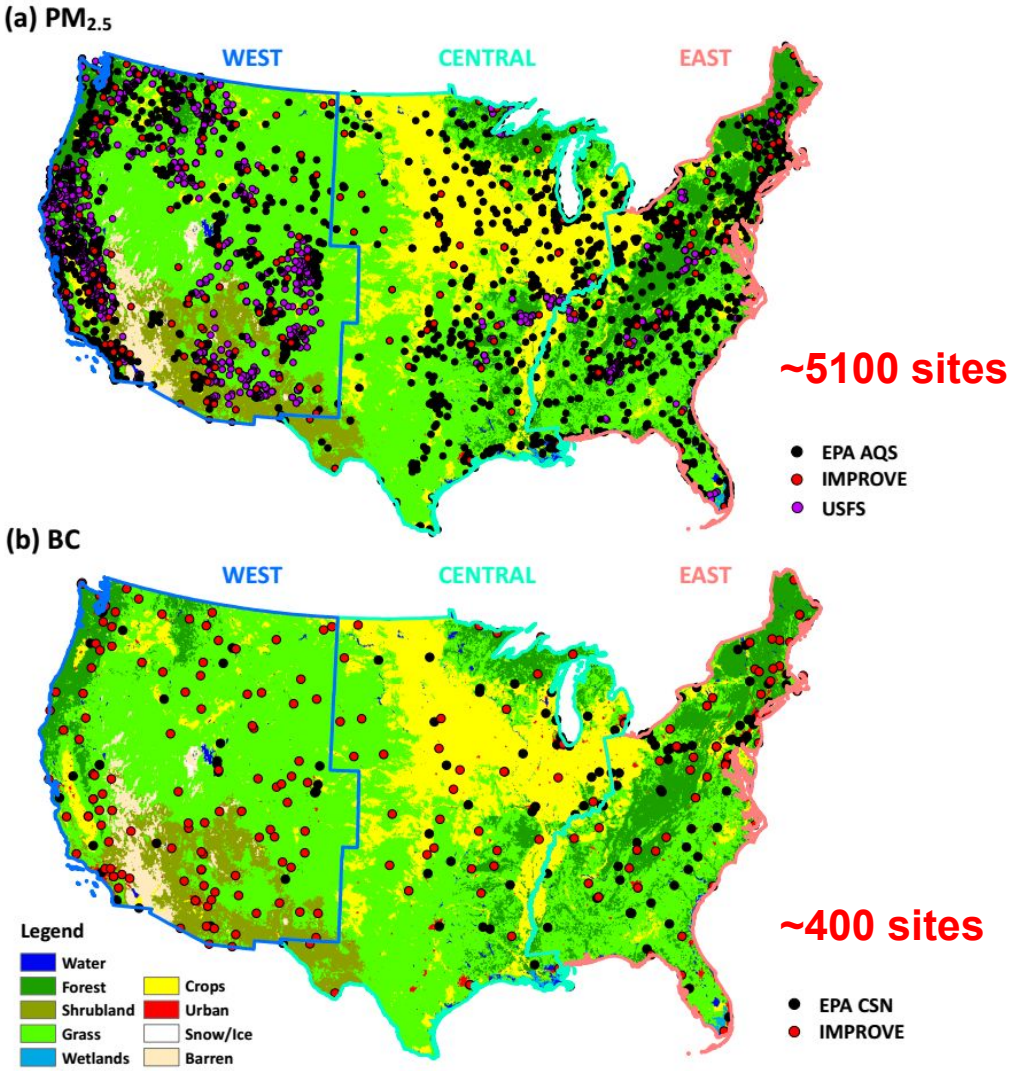
The long-term improvement trends in air quality and public health in the US were obscured in the past decade by the increase of fire emissions that potentially counterbalanced the decline in anthropogenic emissions.

- How have the surface $PM_{2.5}$ mass and its fraction of BC changed in the past two decades in the continental US?
- how much change (if any) in mortality burden due to $PM_{2.5}$ exposure may be attributed to fires?

We tackle both questions by building upon the advances enabled by deriving surface 1 km $PM_{2.5}$ and BC from 2000 to 2020 in the US with full spatial coverage via the **deep learning** approach and estimated the mortality burden.

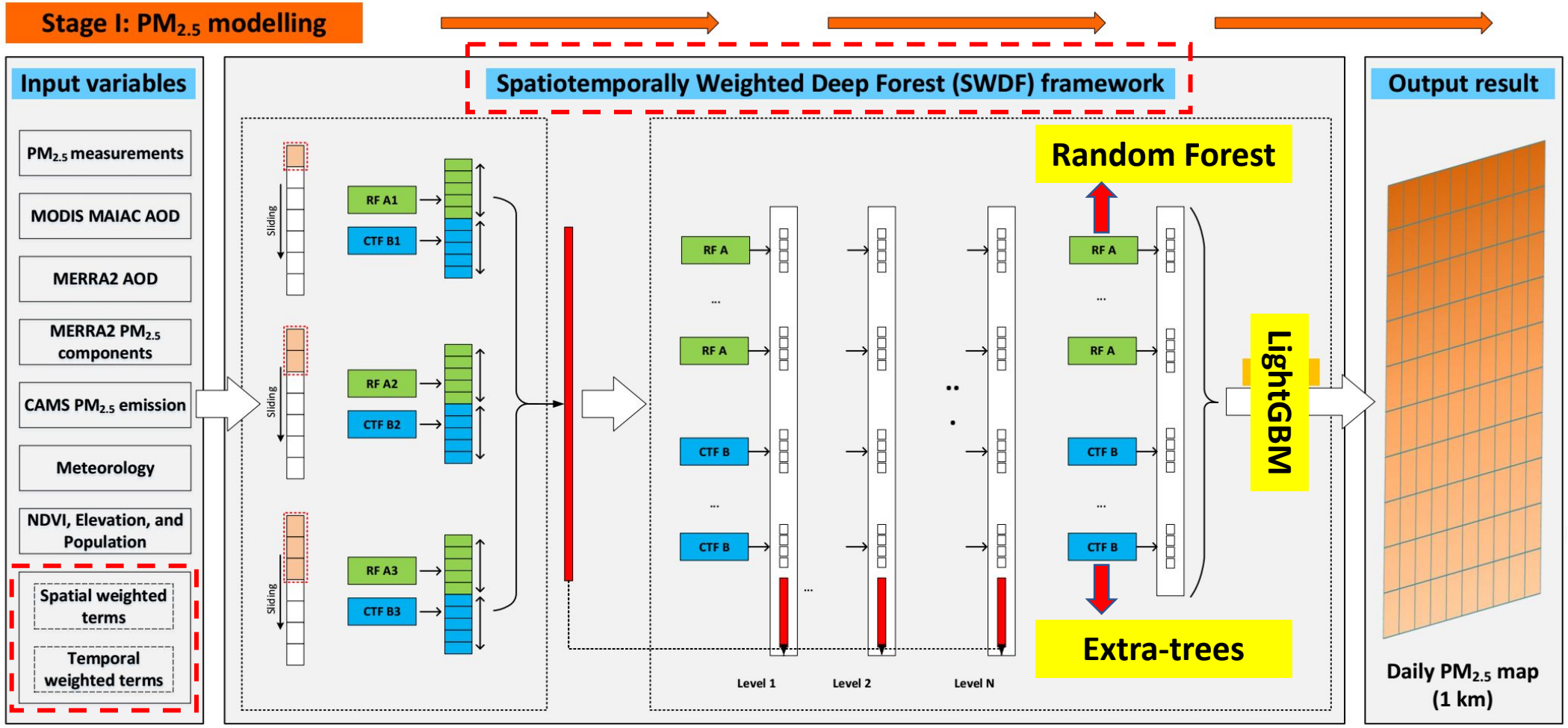
Ground truth: three national networks, including US Forest Service (USFS) AirSis & Western Regional Climate Center (WRCC) network to enhance AI modeling during **wildfire smoke events**.

Total ≈ 5,500 sites



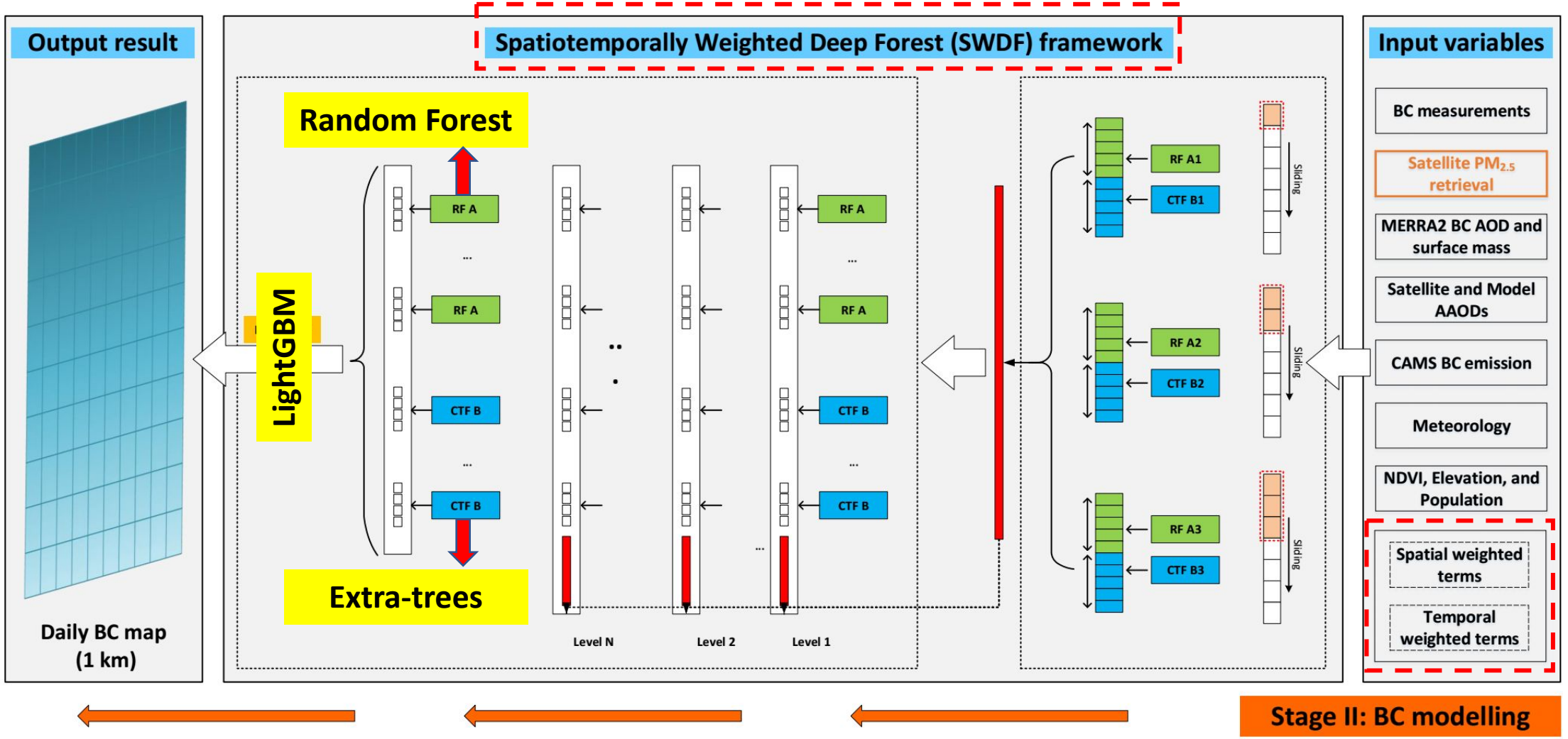
Model development (Stage I)

- We derived gapless daily $PM_{2.5}$ by training the SWDF model to build the **nonlinear relationships** between $PM_{2.5}$ measurements and satellite AOD together with $PM_{2.5}$ components, meteorology, anthropogenic emissions of $PM_{2.5}$ precursors, and land-use and population variables.
- **MAIAC AOD** was the primary input, and **MERRA2 AOD** data is used to fill the satellite gaps where MAIAC AOD was missing.



Model development (Stage II)

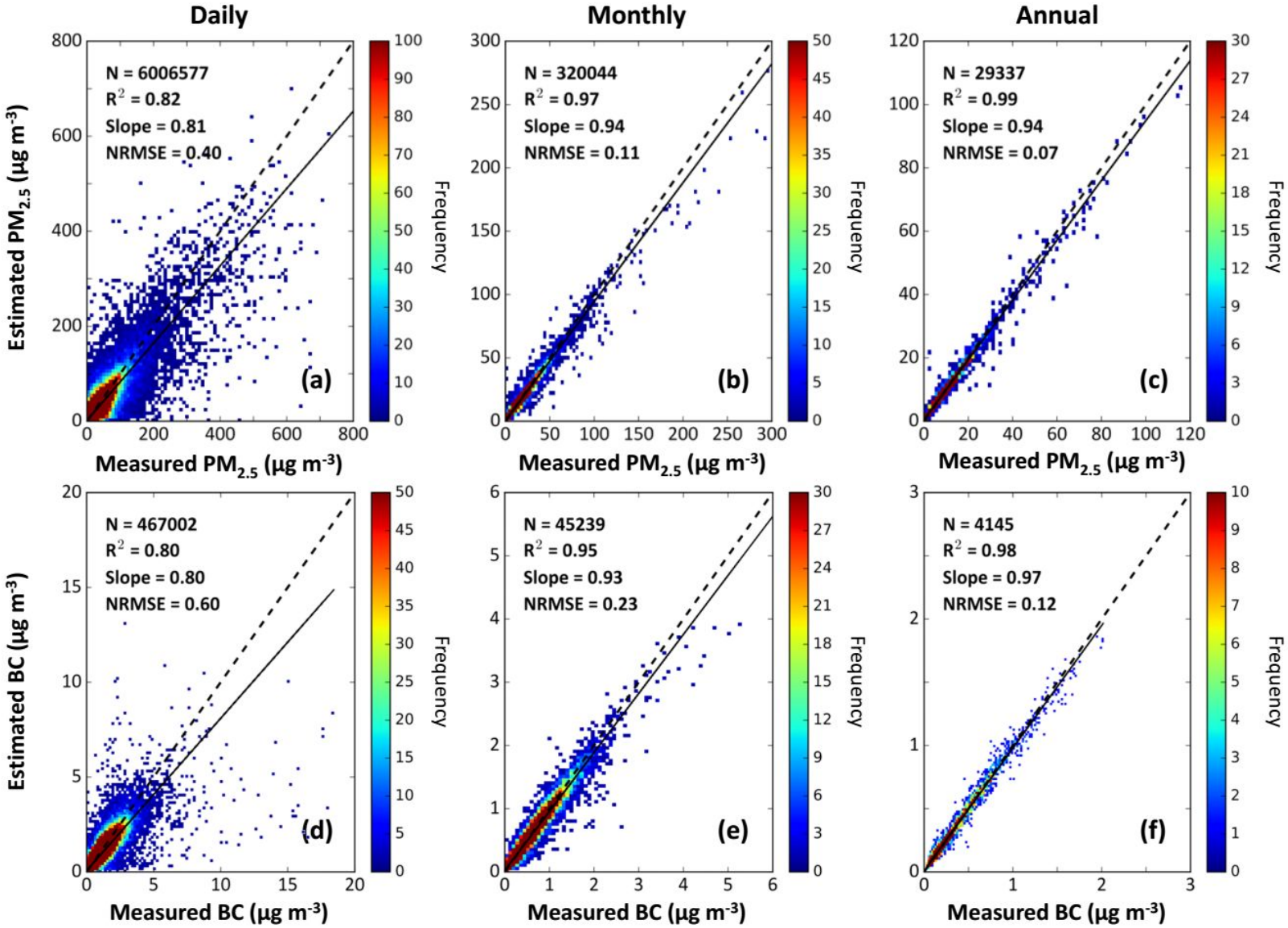
- Once $PM_{2.5}$ estimates were made, they were subsequently used as the main **constraint** in the SWDF model to predict BC mass concentration. Additional factors **highly associated with BC**, e.g., satellite and modelled absorbing AOD, and MERRA2 BC AOD, and BC surface mass simulations and emissions, were also used as inputs in training.



10-fold cross-validation (randomly)

Training: 9 folds

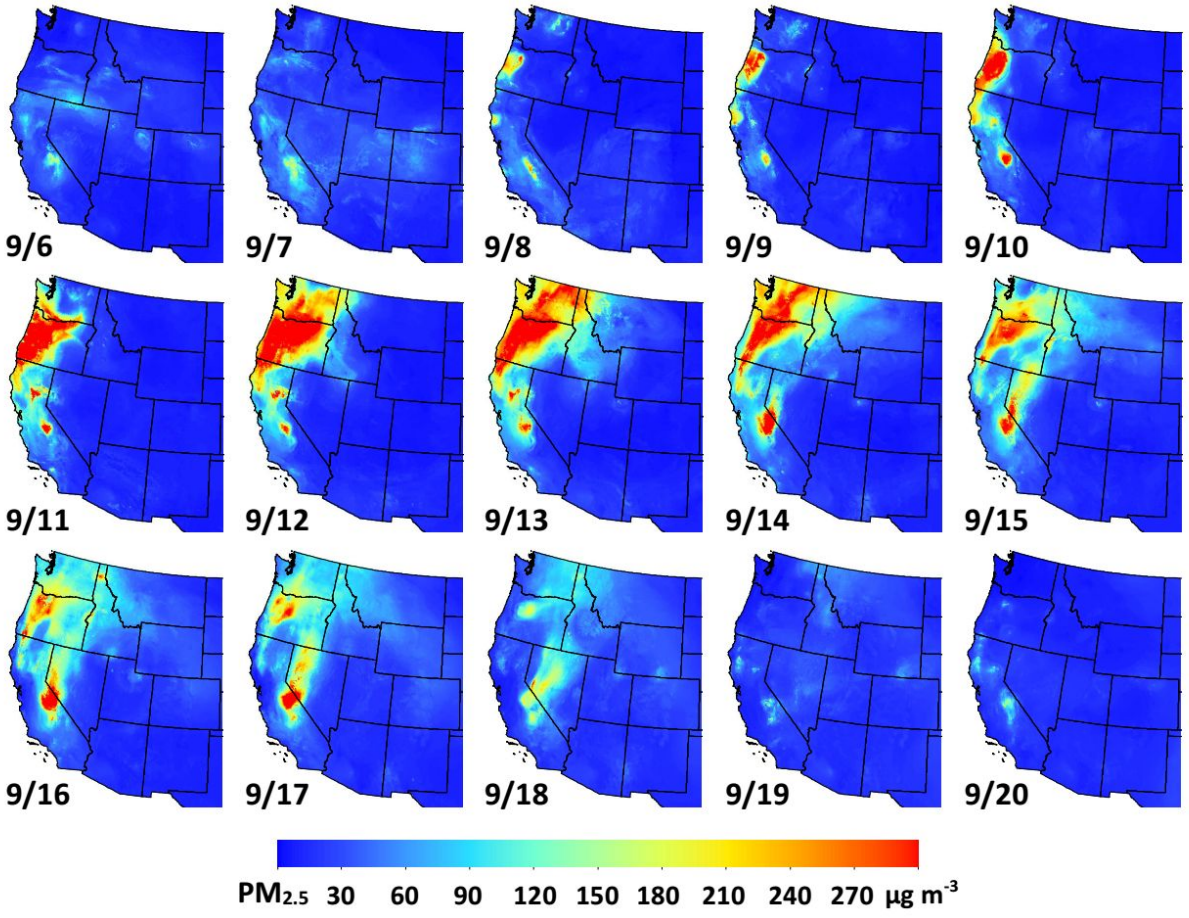
Testing: left-out 1 fold



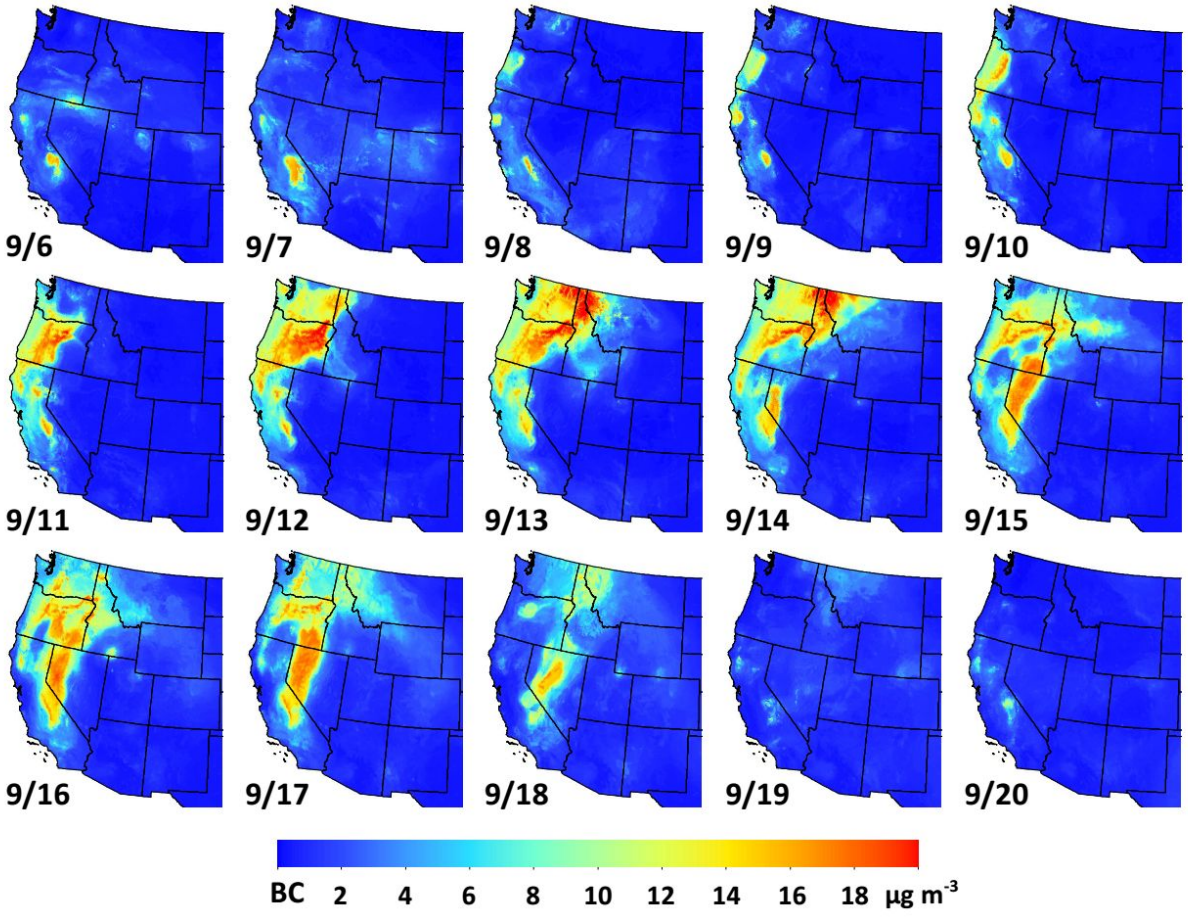
Daily (monthly) $PM_{2.5}$ and BC estimates are reliable, with CV-R^2 of 0.82 (0.97) and 0.80 (0.95), respectively.

Day-to-day evolution of wildfires in western US (2020)

Daily gapless $PM_{2.5}$ maps

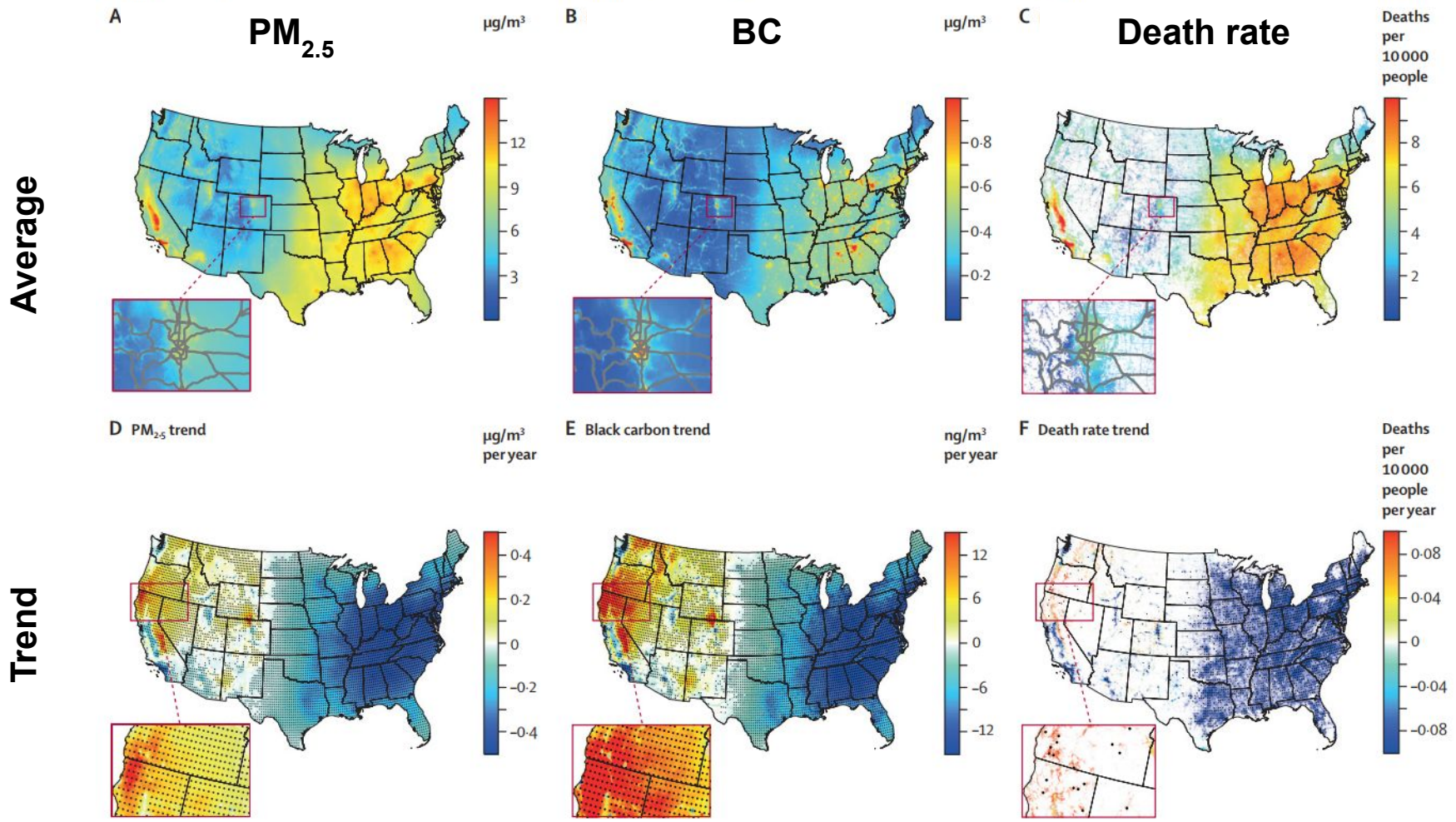


Daily gapless BC maps



They provide valuable insights into the **life cycle of smoke particles**, including their formation, their local spread and long-range transport to downstream regions, and eventual disappearance from the atmosphere.

Annual Trends in $PM_{2.5}$, BC, and Mortality Burden (2000–2020)



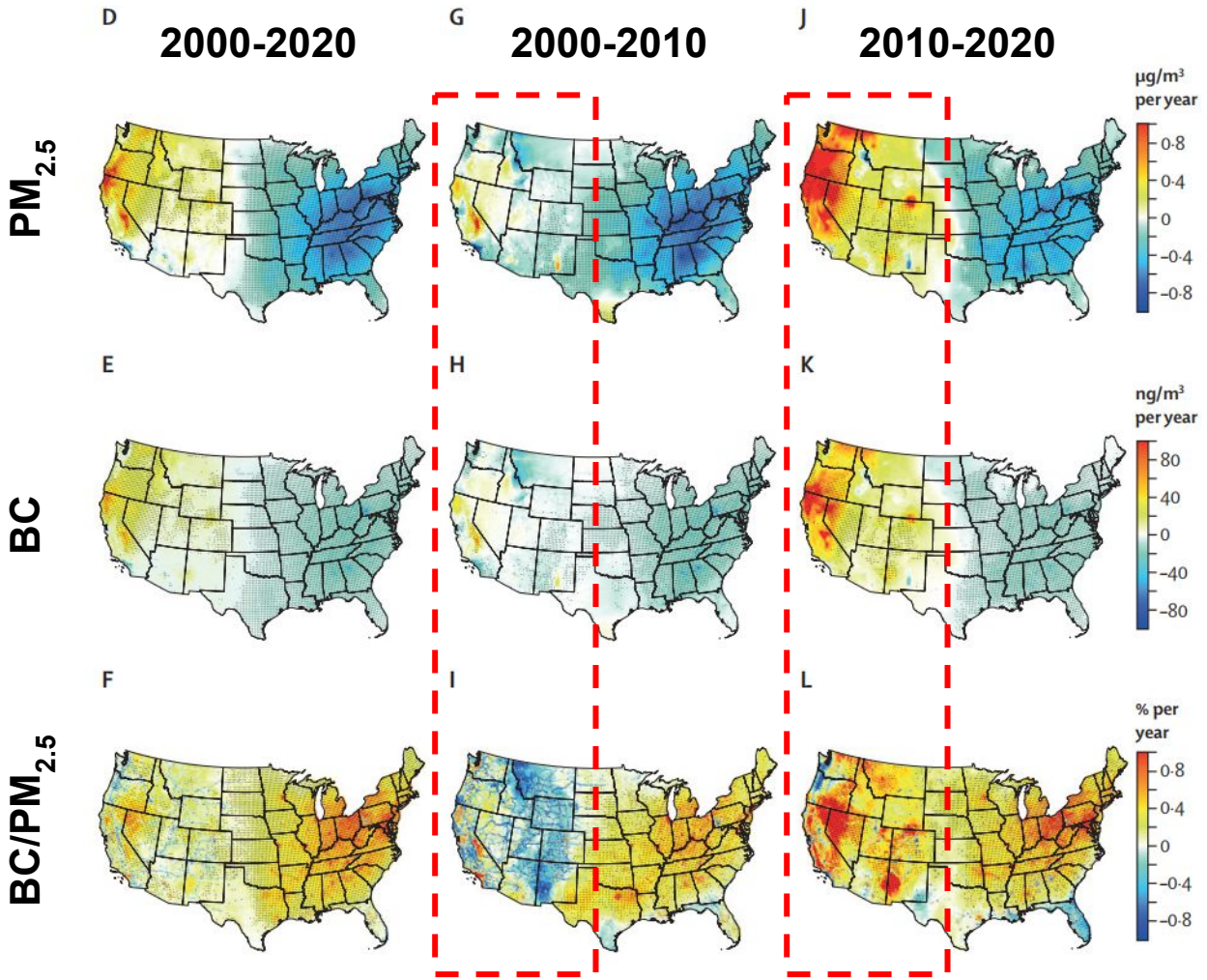
Concentration–response function:

$$MB = \frac{RR - 1}{RR} \times BMR \times POP$$

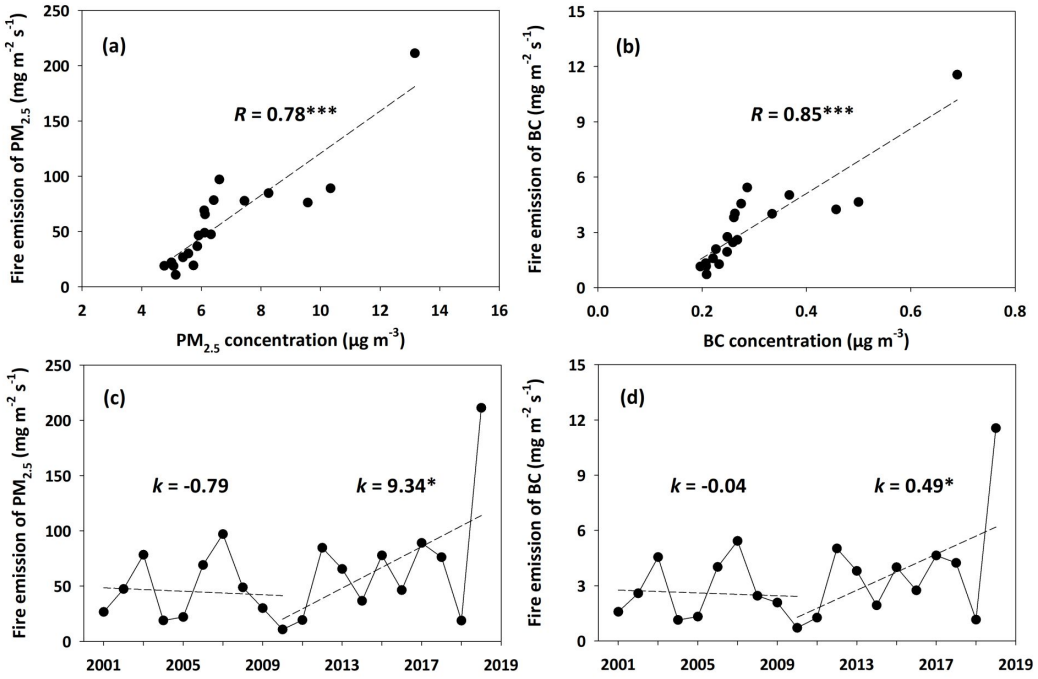
RR (relative risk): from a recent **cohort study** in the USA

- High BC concentrations along highways due to traffic-related emissions (from diesel trucks) are **well captured**.
- Annual $PM_{2.5}$ and BC show steadily **declining** trends in EUS, significant **increasing** trends were found in WUS.
- Death rates **reduced** in EUS; it shows notable rises in eastern and northern California, as well as southwestern Oregon, where elevated levels of $PM_{2.5}$ and BC are evident.

Fire-season $PM_{2.5}$, BC, and BC/$PM_{2.5}$ ratio trends



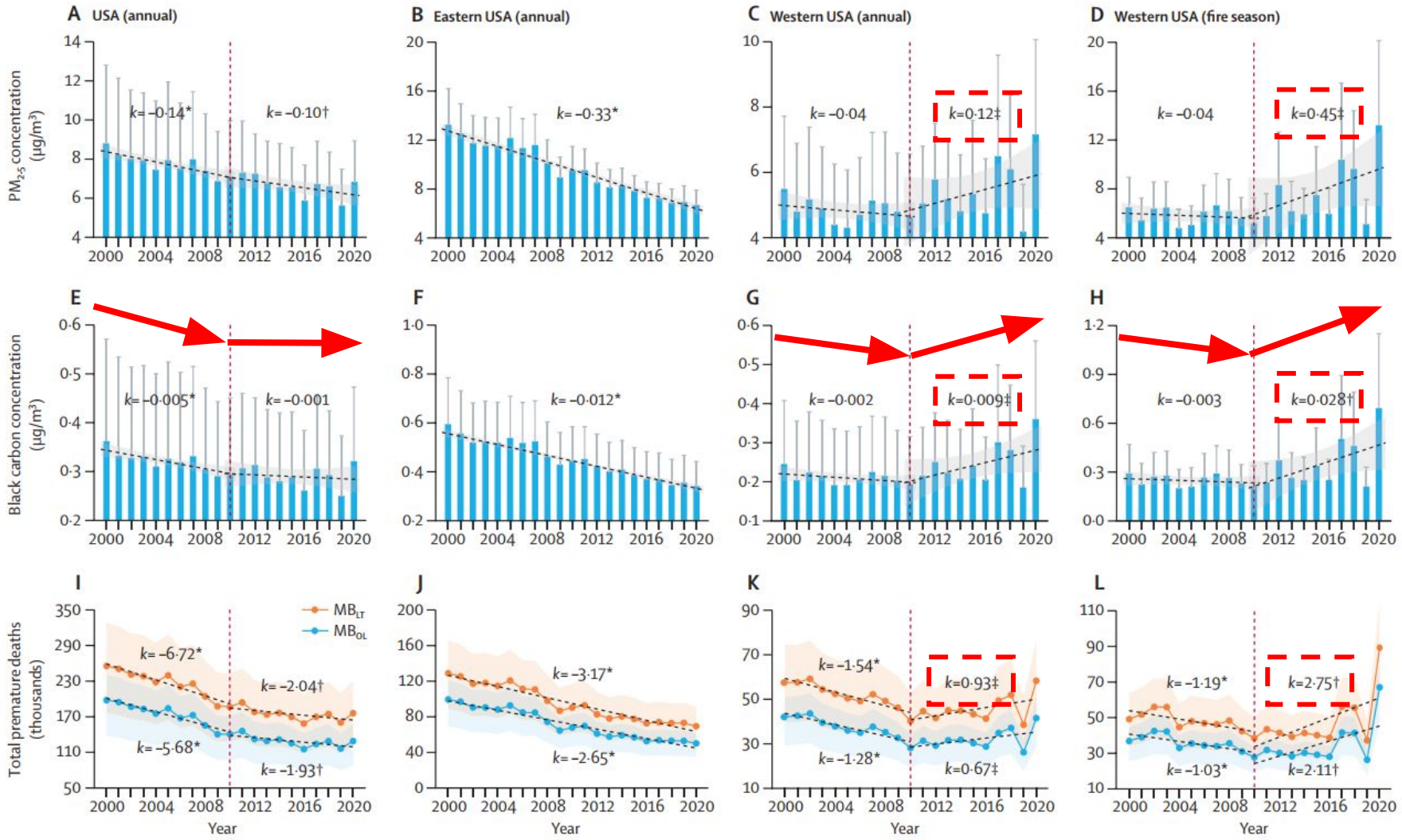
Comparison vs. FEER fire emissions



Strong correlations and consistent changes between $PM_{2.5}$ and BC and their emissions from wildfires

- During the first decade, there was a significant **overall reduction** across the WUS, particularly in the central and southern areas. However, a **dramatic reversal** occurred with **sharp increase** in the second decade.
- BC-to-$PM_{2.5}$ ratio in Fire Season for the US as a whole shows a **significant increase**, primarily for the reduction of inorganic emissions and suggesting a potential **increase** in relative **toxicity** of $PM_{2.5}$.

Time series variations in $PM_{2.5}$, BC, and Mortality Burden



- A **national slowdown** and a **regional reversal** in the WUS of the decreasing trends of air quality and mortality burden.
- The fire-season air pollution and health burden surpassed **3–4 times** the annual averages;

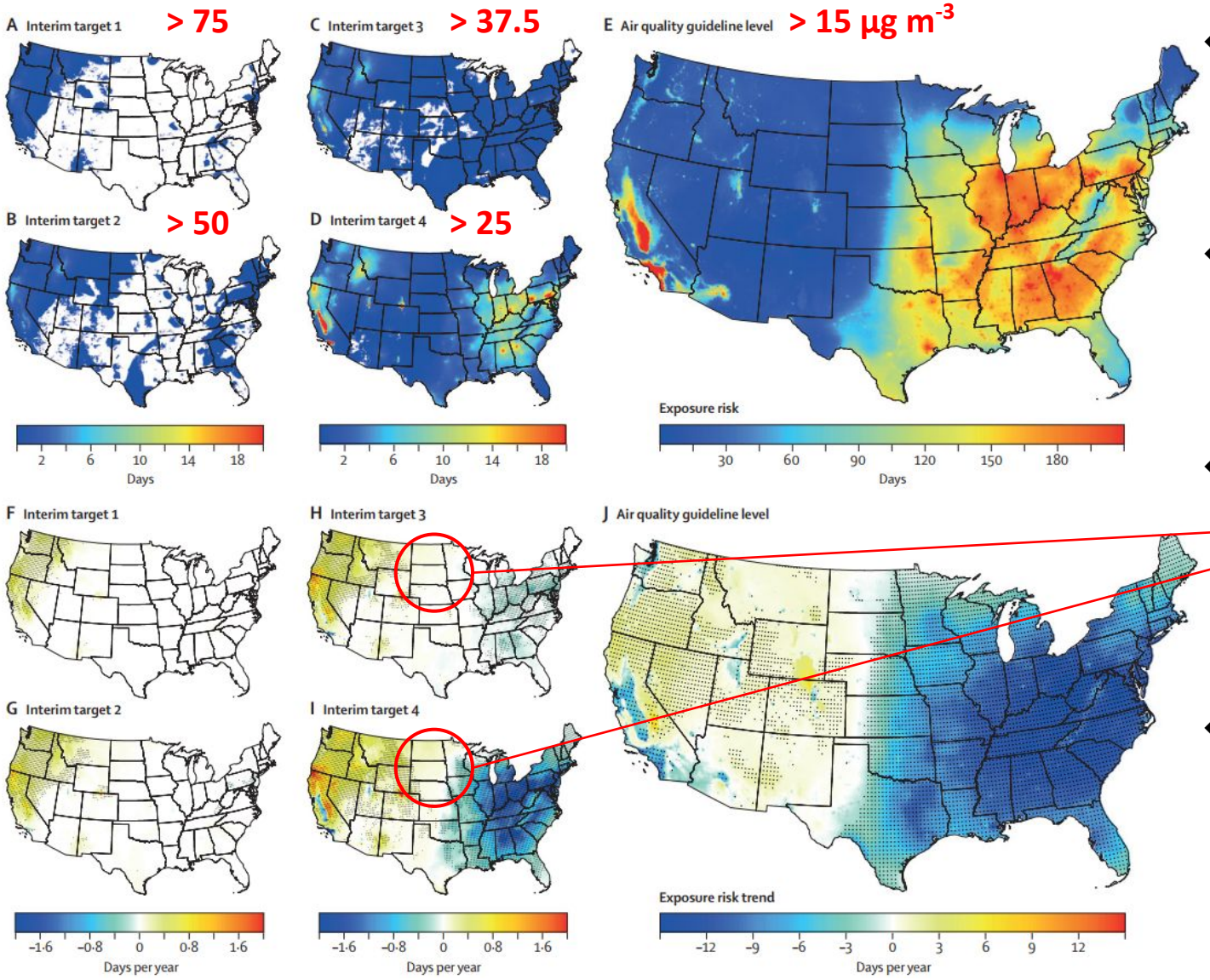
- When the greater toxicity of BC is (not) considered, $PM_{2.5}$ led to an increase of ~930 (670) deaths per year in the western US. This is over **10 times higher** than the number of casualties directly caused by wildfires (~89 deaths per year in the US).
- The health benefits from air quality improvement measures are **significantly offset** by wildfires.

Short-term daily exposure risk assessment

Percentage of days exceeding the WHO daily air quality standards

Multi-year Mean

Temporal trends



- During 2000-2020, **100**%, 99%, and 86% of US populated areas would experience unhealthy air exposure risk for at least 1, 7, and 30 days.
- Emissions from increasing wildfires play a crucial role in the **increase of daily exposure risk** in the northwestern US and California.
- More importantly, an **increase** in polluted days in the **Midwestern US** was also observed, possibly due to the long-range wildfire smoke-particle transport from the WUS .
- If wildfires in the western US are not effectively controlled, people in the eastern US will be **affected** due to long-distance transmission (e.g., **Eastern Canada wildfires**).

Our findings were reported by >70 Major Medias

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Air quality had gotten better in parts of the U.S. – but wildfire smoke is reversing those improvements, researchers say

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Wildfires have offset 20 years of air quality gains in US West: study

BY SHARON UDASIN - 12/04/23 6:40 PM ET

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Wildfire smoke threatens to undo improvemer pollution, study finds

Nicole Karlis
Tue, December 5, 2023 at 11:00 AM EST · 2 min read

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Wildfires Are Undoing Gains Mad Pollution

By HealthDay | Dec. 5, 2023, at 8:37 a.m.

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By Dennis Thompson HealthDay Reporter

TUESDAY, Dec. 5, 2023 (HealthDay News) -- Unhealthy air from wildfires is causing hundreds of additional deaths in the western United States every year, a new study claims.

Wildfires have undercut progress made in cleaning America's air, and between 2000 and 2020 caused an increase of 670 premature deaths each year in the West, researchers report Dec. 4 in *The Lancet Planetary Health* journal.

(HEALTHDAY)

NEWS RELEASE 4-DEC-2023

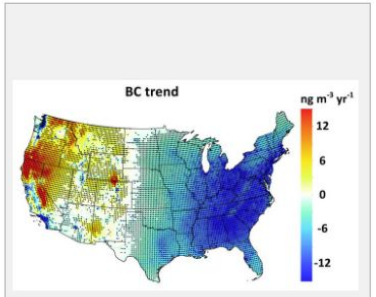
Wildfires have erased two decades' worth of air quality gains in western United States

Study finds fire-prone areas and downwind regions have seen an increase of premature deaths

Peer-Reviewed Publication
UNIVERSITY OF IOWA

You need only to remember last summer's wildfires in the United States and Canada, which fouled the air from coast to coast, to know the effects these blazes can have on the environment and human health.

A new study has tabulated the toll from two decades of wildfires on air quality and human health in the continental U.S. The authors report that from 2000 to 2020, the air has worsened in the western U.S., mainly



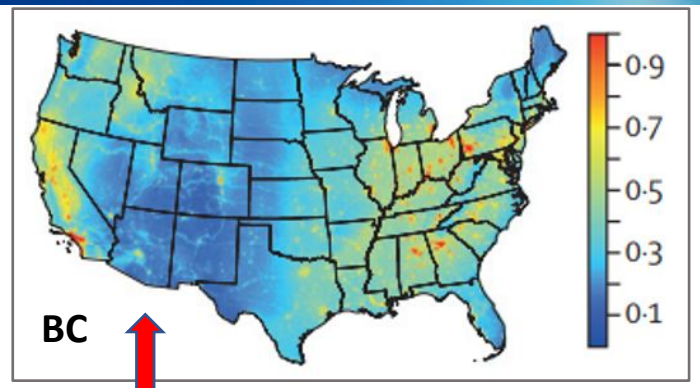
Global daily $PM_{2.5}$ and composition from MODIS (1 km)

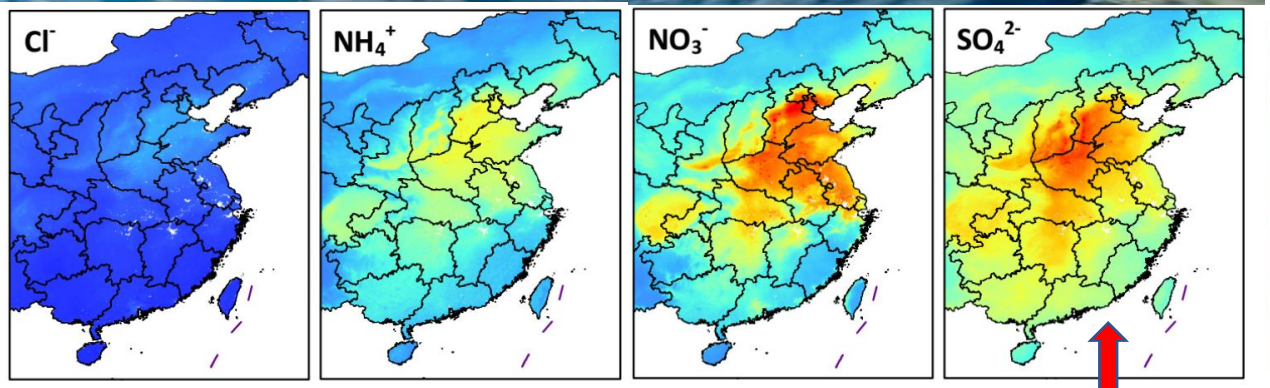
$PM_{2.5}$ composition

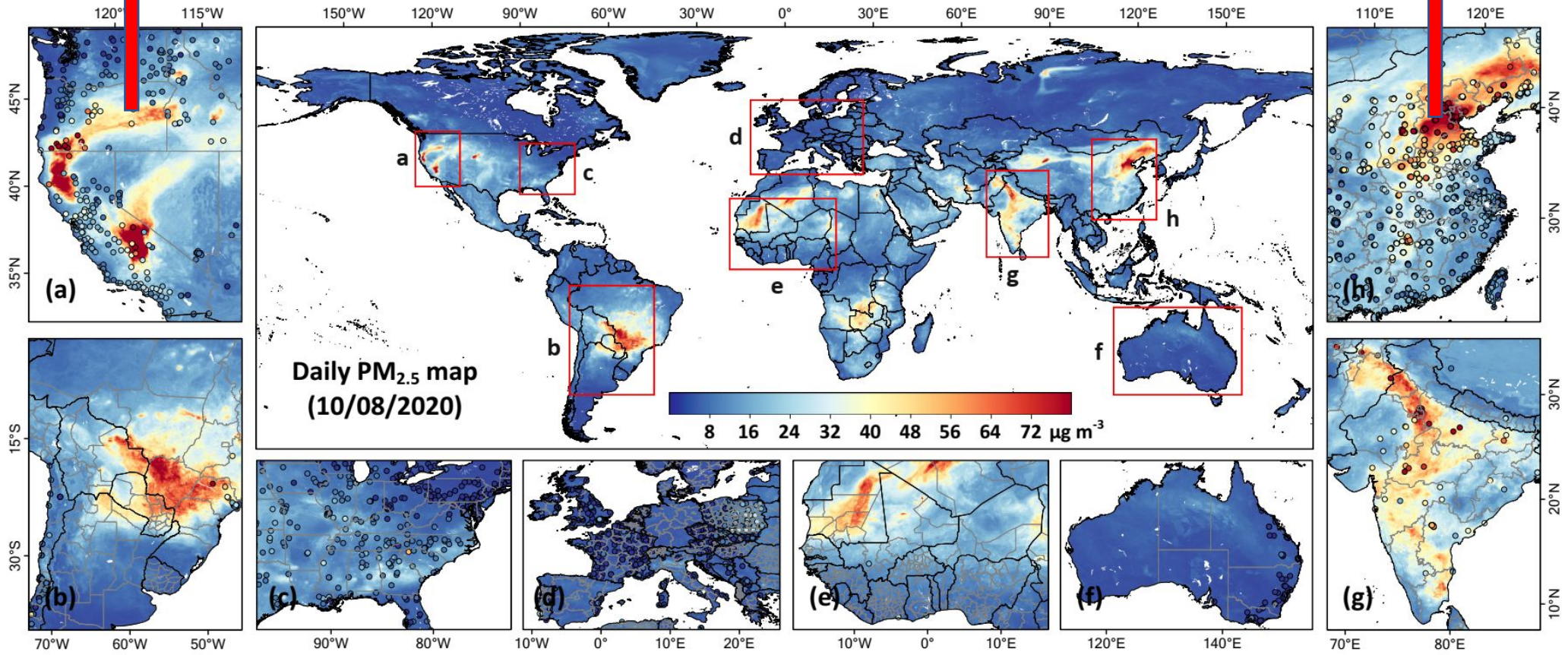
Regional scale

Total $PM_{2.5}$ mass

Global scale

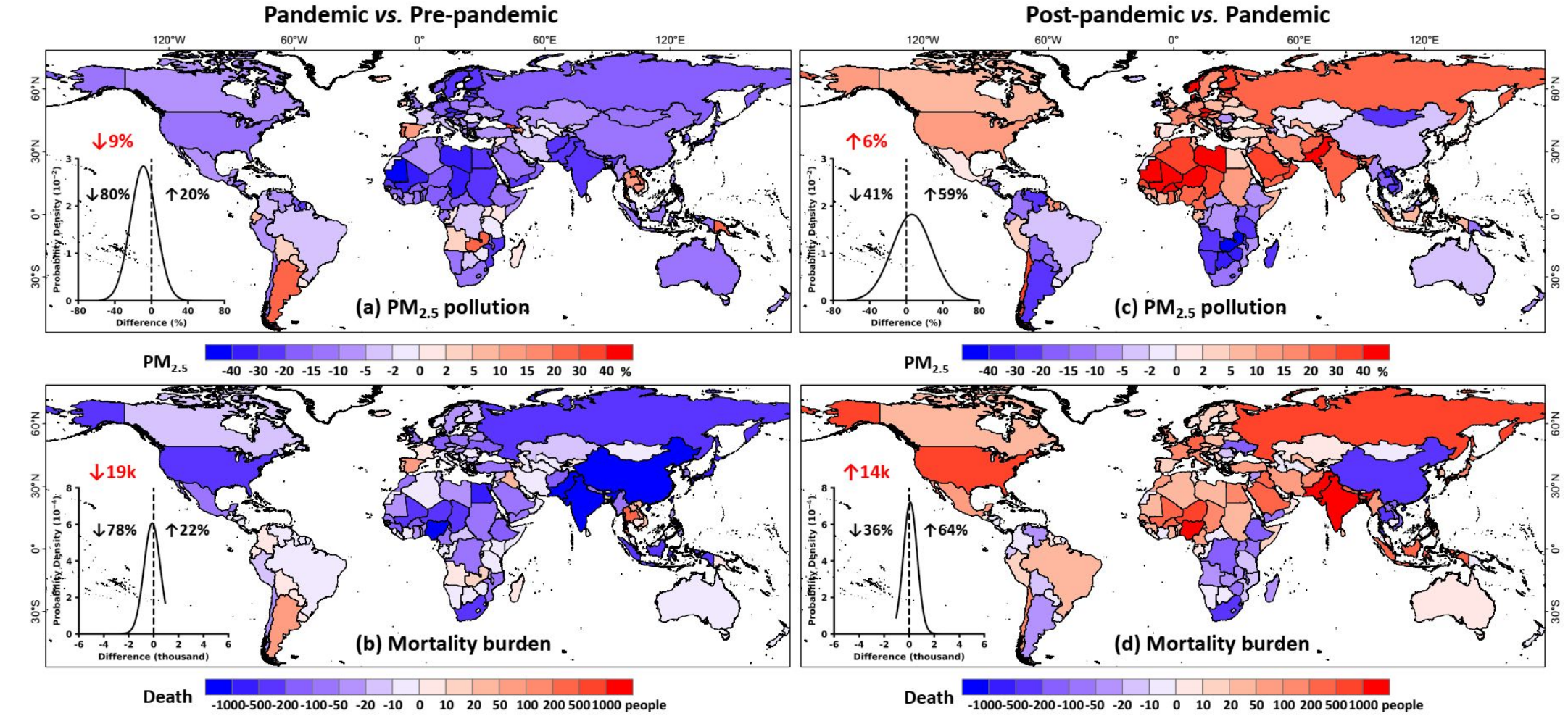






Wei et al., *NC*, 2023; *LPH*, 2023; *EST*, 2023;

Short-term $PM_{2.5}$ and mortality change during COVID-19 lockdown



- $PM_{2.5}$ pollution in **80%** of countries has decreased, presumably in response to the implementation of the strictest lockdown measures, saving approximately 19.0 thousand lives.
- After the pandemic, **59%** of countries experienced a rebound in $PM_{2.5}$ than 2020, resulting in 14.4 thousand lives lost; merely **32%** of countries have reverted to the $PM_{2.5}$ levels experienced prior to the pandemic.

Wei et al., *NC*, 2023

nature communications

$PM_{2.5}$

Article

https://doi.org/10.1038/s41467-023-43862-3

First close insight into global daily gapless 1 km $PM_{2.5}$ pollution, variability, and health impact

Received: 30 April 2023

Accepted: 22 November 2023

Published online: 15 December 2023

Jing Wei[1], Zhanqing Li[1], Alexei Lyapustin[2], Jun Wang[3], Oleg Dubovik[4], Joel Schwartz[5], Lin Sun[6], Chi Li[7], Song Liu[8] & Tong Zhu[9]

ENVIRONMENTAL Science & Technology

$PM_{2.5}$ composition

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Article

Separating Daily 1 km $PM_{2.5}$ Inorganic Chemical Composition in China since 2000 via Deep Learning Integrating Ground, Satellite, and Model Data

Jing Wei,* Zhanqing Li,* Xi Chen,* Chi Li, Yele Sun, Jun Wang, Alexei Lyapustin, Guy Pierre Brasseur, Mengjiao Jiang, Lin Sun, Tao Wang, Chang Hoon Jung, Bing Qiu, Cuilan Fang, Xuhui Liu, Jinrui Hao, Yan Wang, Ming Zhan, Xiaohong Song, and Yuewei Liu

Cite This: *Environ. Sci. Technol.* 2023, 57, 18282–18295

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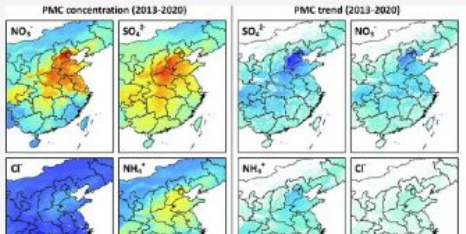
ABSTRACT: Fine particulate matter ($PM_{2.5}$) chemical composition has strong and diverse impacts on the planetary environment, climate, and health. These effects are still not well understood due to limited surface observations and uncertainties in chemical model simulations. We developed a four-dimensional spatiotemporal deep forest (4D-STDF) model to estimate daily $PM_{2.5}$ chemical composition at a spatial resolution of 1 km in China since 2000 by integrating measurements of $PM_{2.5}$ species from a high-density observation network, satellite $PM_{2.5}$ retrievals, atmospheric reanalyses, and model simulations. Cross-validation results illustrate the reliability of sulfate



ENVIRONMENTAL Science & Technology

Surface NO_2

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Article

Ground-Level NO_2 Surveillance from Space Across China for High Resolution Using Interpretable Spatiotemporally Weighted Artificial Intelligence

Jing Wei,*[,‖,‖] Song Liu,[‖,‖] Zhanqing Li,* Cheng Liu, Kai Qin, Xiong Liu, Rachel T. Pinker,

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Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

Surface O_3

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Full-coverage mapping and spatiotemporal variations of ground-level ozone (O_3) pollution from 2013 to 2020 across China

Jing Wei[a,b,*], Zhanqing Li[a,*], Ke Li[c], Russell R. Dickerson[a], Rachel T. Pinker[a], Jun Wang[b], Xiong Liu[d], Lin Sun[e], Wenhao Xue[f], Maureen Cribb[a]

Atmos. Chem. Phys., 23, 1511–1532, 2023
https://doi.org/10.5194/acp-23-1511-2023

Atmospheric Chemistry and Physics — Open Access — EGU

Surface SO_2 and CO

Research article

Ground-level gaseous pollutants (NO_2, SO_2, and CO) in China: daily seamless mapping and spatiotemporal variations

Jing Wei[1], Zhanqing Li[1], Jun Wang[2], Can Li[1], Pawan Gupta[3,4], and Maureen Cribb[1]

[1]Department of Atmospheric and Oceanic Science, Earth System Science Interdisciplinary Center,

References ($PM_{2.5}$ and gases) [Citations]

- **Wei, J.***, Wang, J.*, Li, Z.*, et al. Long-term mortality burden trends attributed to black carbon and $PM_{2.5}$ from wildfire emissions across the continental USA from 2000 to 2020: a deep learning modelling study. *The Lancet Planetary Health*, **2023**, 7, e963–e975.
- **Wei, J.***, Li, Z.*, Lyapustin, A., et al. First close insight into global daily gapless 1 km $PM_{2.5}$ pollution, variability, and health impact. *Nature Communications*, **2023**, 14, 8349.
- **Wei, J.**, Li, Z.*, et al. Reconstructing 1-km-resolution high-quality $PM_{2.5}$ data records from 2000 to 2018 in China: spatiotemporal variations and policy implications. *Remote Sensing of Environment*, **2021**, 252, 112136. **(ESI Hot and Highly Cited Paper)** **[522]**
- **Wei, J.**, Huang, W., Li, Z.*, et al. Estimating 1-km-resolution $PM_{2.5}$ concentrations across China using the space-time random forest approach. *Remote Sensing of Environment*, **2019**, 231, 111221. **(ESI Hot and Highly Cited Paper)** **[394]**
- **Wei, J.**, Li, Z.*, Cribb, M., et al. Improved 1 km resolution $PM_{2.5}$ estimates across China using enhanced space-time extremely randomized trees. *Atmospheric Chemistry and Physics*, **2020**, 20, 3273–3289. **(ESI Hot and Highly Cited Paper)** **[366]**
- **Wei, J.***, Li, Z.*, et al. Full-coverage mapping and spatiotemporal variations of ground-level ozone (O_3) pollution from 2013 to 2020 across China. *Remote Sensing of Environment*, 2022, 270, 112775. **(ESI Hot and Highly Cited Paper)** **[230]**
- **Wei, J.**, Li, Z.*, et al. Satellite-derived 1-km-resolution PM_1 concentrations from 2014 to 2018 across China. *Environmental Science & Technology*, **2019**, 53(22), 13265–13274. **(ESI Hot and Highly Cited Paper)** **[212]**
- **Wei, J.***, Liu, S., Li, Z.*, …, and Wang, J.*. Ground-level NO_2 surveillance from space across China for high resolution using interpretable spatiotemporally weighted artificial intelligence. *Environmental Science & Technology*, **2022**, 56(14), 9988–9998. **(ESI Highly Cited Paper)** **[97]**
- **Wei, J.***, Li, Z.*, et al. Ground-level gaseous pollutants (NO_2, SO_2, and CO) in China: daily seamless mapping and spatiotemporal variations. *Atmospheric Chemistry and Physics*, **2023**, 23, 1511–1532. **(ESI Hot and Highly Cited Paper)** **[80]**

Online data sharing and applications

Jing Wei | Chinese

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GlobalHighAirPollutants (GHAP) | ChinaHighAirPollutants (CHAP) | USHighAirPollutants (USHAP)

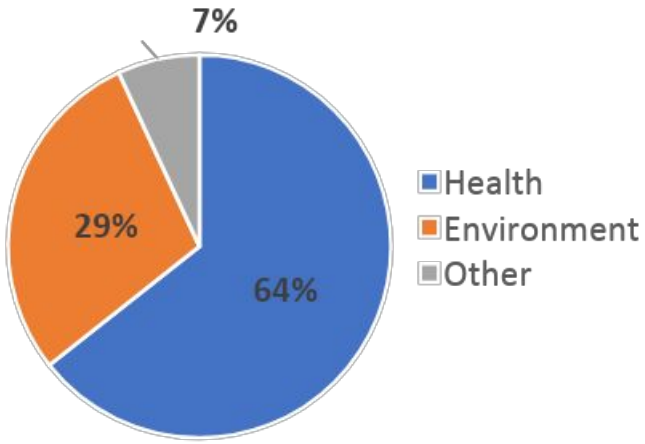
ChinaHighAirPollutants (CHAP)

- **Brief Introduction**

  The ChinaHighAirPollutants (CHAP) dataset refers to the **long-term**, **full-coverage**, **high-resolution**, and **high-quality** datasets of ground-level air pollutants for China. It is generated from the big data (e.g., ground-based measurements, satellite remote sensing products, atmospheric reanalysis, and model simulations) using artificial intelligence by considering the spatiotemporal heterogeneity of air pollution. The CHAP dataset contains **7** major air pollutants (i.e., **PM_1**, **$PM_{2.5}$**, **PM_{10}**, **O_3**, **NO_2**, **SO_2**, and **CO**), **$PM_{2.5}$ chemical composition (i.e., SO_4^{2-}, NO_3^-, NH_4^+, Cl^-, BC, and OM)**, and ambient **polycyclic aromatic hydrocarbons (PAHs)**, including 7 carcino
  BaA, **Chr**, **BbF**, **BkF**, **BaP**, **DahA**, **IcdP**). This CHAP dataset is **public** and **freely** open to all users!

- **Open Platform**

https://weijing-rs.github.io/product.html



The global and regional air quality datasets have been widely used in environmental health studies, among others, by **hundreds** of institutions!

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GHAP: Global High-resolution and High-quality Ambient Air Pollutants Dataset over Land

Published April 11, 2022 | Version 1 — Dataset — Open

GlobalHighPM2.5: Big Data Gapless 1 km Global Ground-level PM2.5 Dataset over Land

Wei, Jing[1]; Li, Zhanqing[1]; Lyapustin, Alexei[2]; Wang, Jun[3]; Dubovik, Oleg[4]; Schwartz, Joel[5]; Sun, Lin[6]; Li, Chi[7]; Liu, Song[8]; Zhu, Tong[9]

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GlobalHighPM2.5 is one of the series of long-term, full-coverage, global high-resolution and high-quality datasets of ground-level air pollutants over land (i.e., GlobalHighAirPollutants, GHAP). It is generated from big data (e.g., ground-based measurements, satellite remote sensing products, atmospheric reanalysis, and model simulations) using artificial intelligence by considering the spatiotemporal heterogeneity of air pollution.

This dataset contains input data, analysis codes, and generated dataset used for the following article, and if you use the GlobalHighPM2.5 dataset for related scientific research, please cite the below-listed corresponding reference (Wei et al., NC, 2023):

- Wei, J., Li, Z., Lyapustin, A., Wang, J., Dubovik, O., Schwartz, J., Sun, L., Li, C., Liu, S., and Zhu, T. First close insight into global daily gapless 1 km $PM_{2.5}$ pollution, variability, and health impact. *Nature Communications*, 2023, 14, 8349. https://doi.org/10.1038/s41467-023-43862-3

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Take-home message

Conclusions:

- We have reconstructed, to date, the longest 1 km daily seamless $PM_{2.5}$ and BC data records (2000 to present) in the US.
- In the past decade, the decline rates of air quality and health burden have slowed down nationally, and have even reversed to increase in the western US, due to increased fire emissions.
- We have also generated global daily high-resolution datasets for both PM and polluted gases from space using AI.

Future plans:

- Integrating **aerosol layer height** into AI-based modeling to enhance $PM_{2.5}$ estimation under smoke conditions.
- Leveraging AI models with high-frequency geostationary earth orbit (GEO) satellite data, such as **GOES-R** and **TEMPO**, to better capture the **diurnal variations** of wildfire events.

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That is all for my talk and thanks for your attention!

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