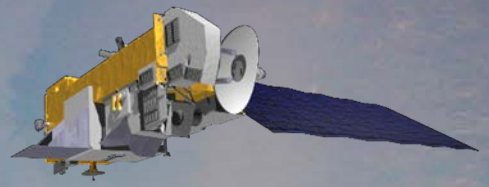
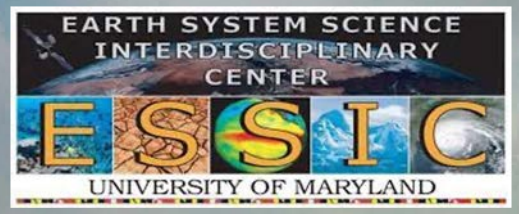


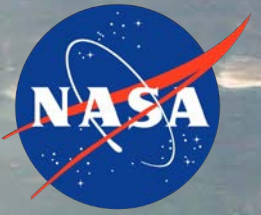
# Tracking Ambient Particulate Matter and Chemical Composition from Space using AI


**Jing Wei & Zhanqing Li**

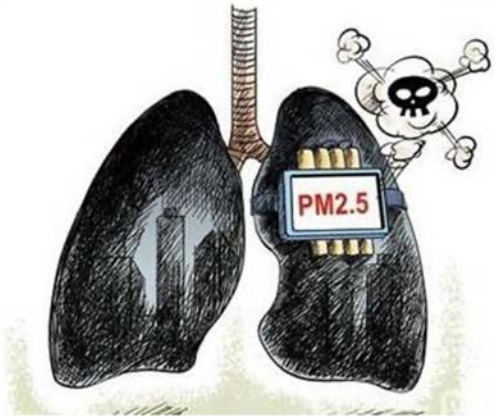
**ESSIC & Department of Atmospheric and Oceanic Science, University of Maryland, College Park, MD, USA**



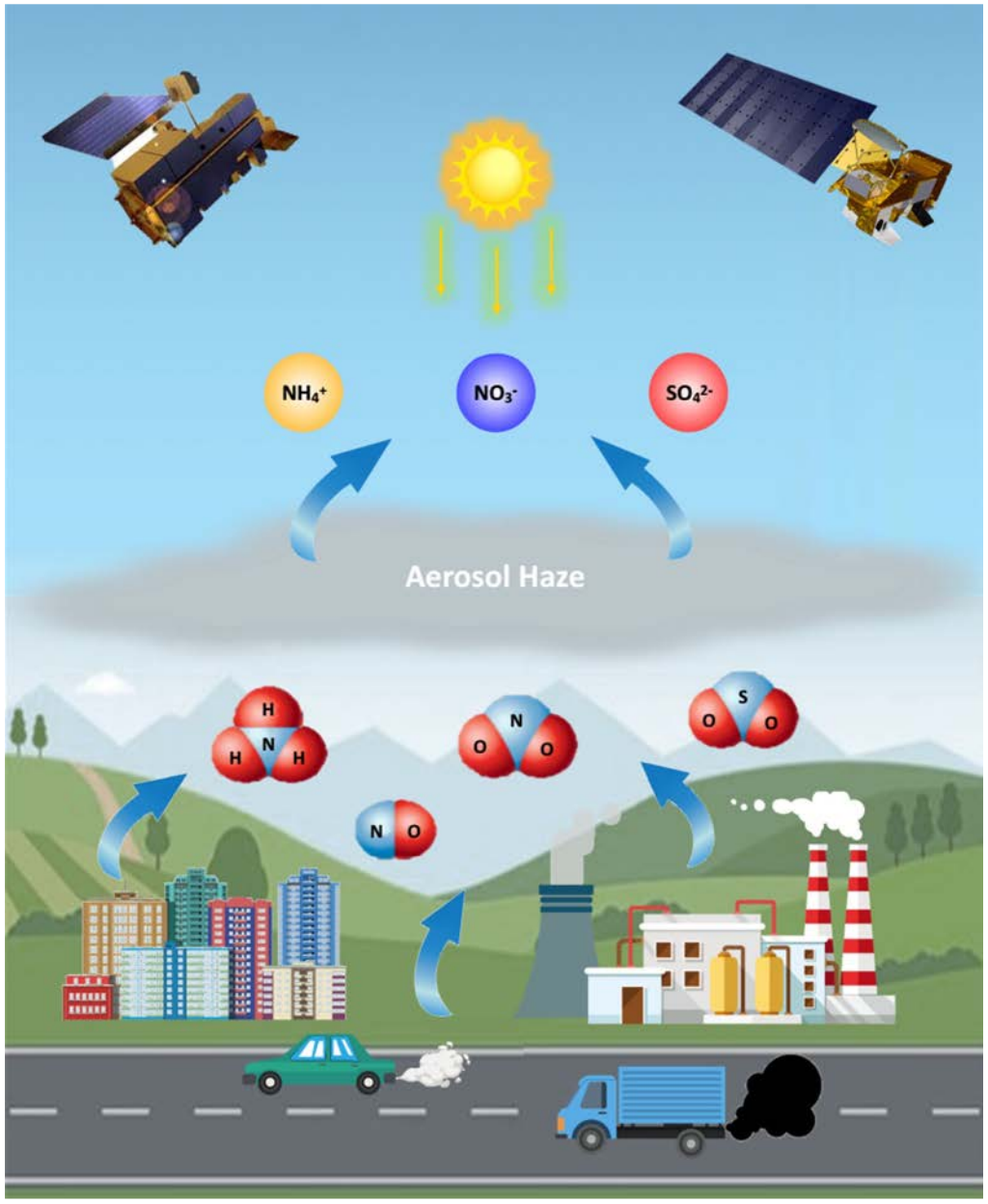




# Ambient Air Pollution


- $PM_{2.5}$ has become an urgent environmental health threat and ranked the **4th** risk factor, especially in developing countries like China.
- $PM_{2.5}$ contains primary and secondary aerosols, and different species impact the public health in different ways.
- Black carbon from wildfires or ultrafine particles from automobile exhaust may have strong toxicities
- The formation of SIA components (sulfate ($SO_4^{2-}$), nitrate ($NO_3^-$), ammonium ($NH_4^+$)) is a main cause of severe haze pollution.
- Their sources are complex, whose estimation is highly challenging.

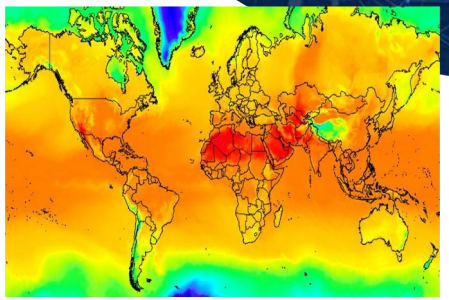


# The era of Big-Data-driven AI has arrived and thrived!

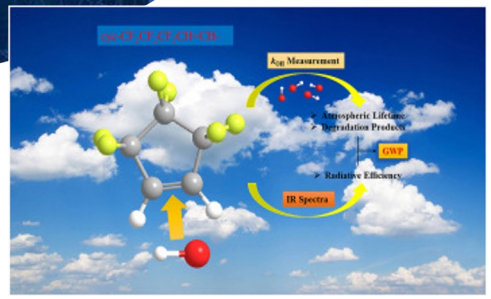
We have developed several state-of-the-art AI (machine and deep learning) tools by considering the **spatiotemporal information of air pollution** to improve estimation accuracies and efficiencies.

**Satellite remote sensing**

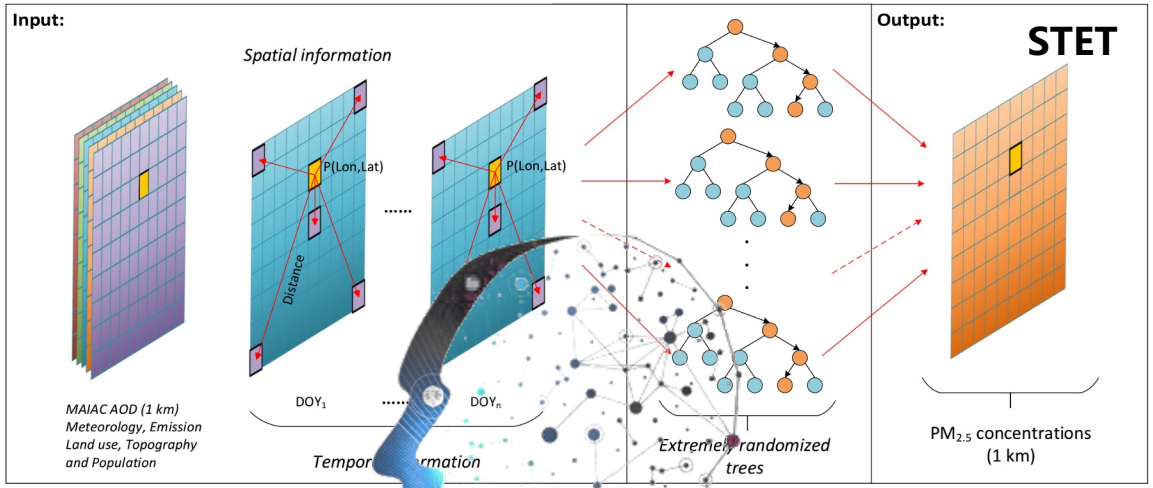

**Ground Measurements**

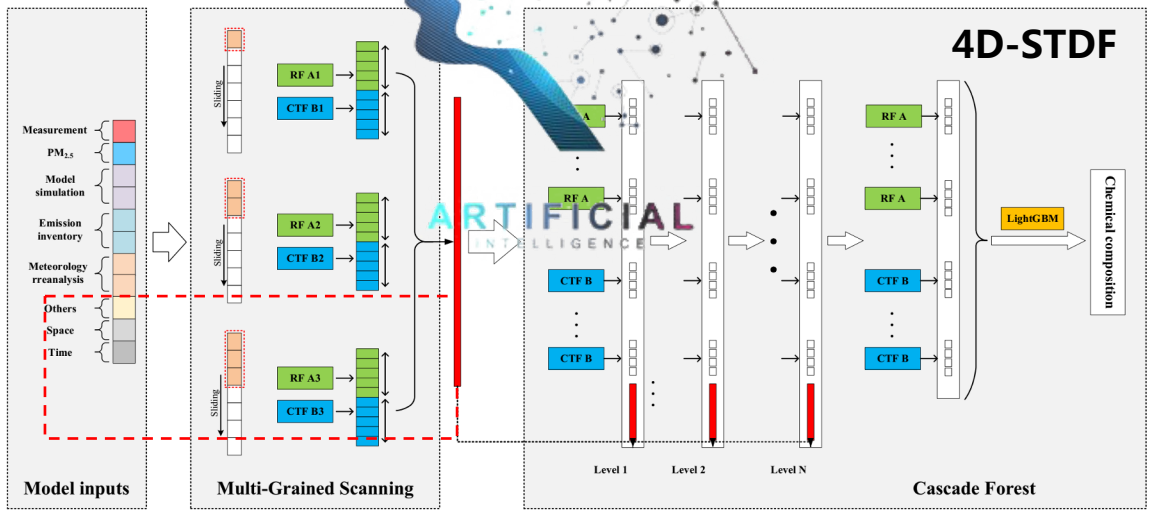



**Atmospheric Reanalysis**




**Model Simulations**



As the #1 source of emissions whose influences spread across the Asia-Pacific rim, China have experienced most dramatic changes in the last a few decades, but country-wide $PM_{2.5}$ records only dated back to 2013.

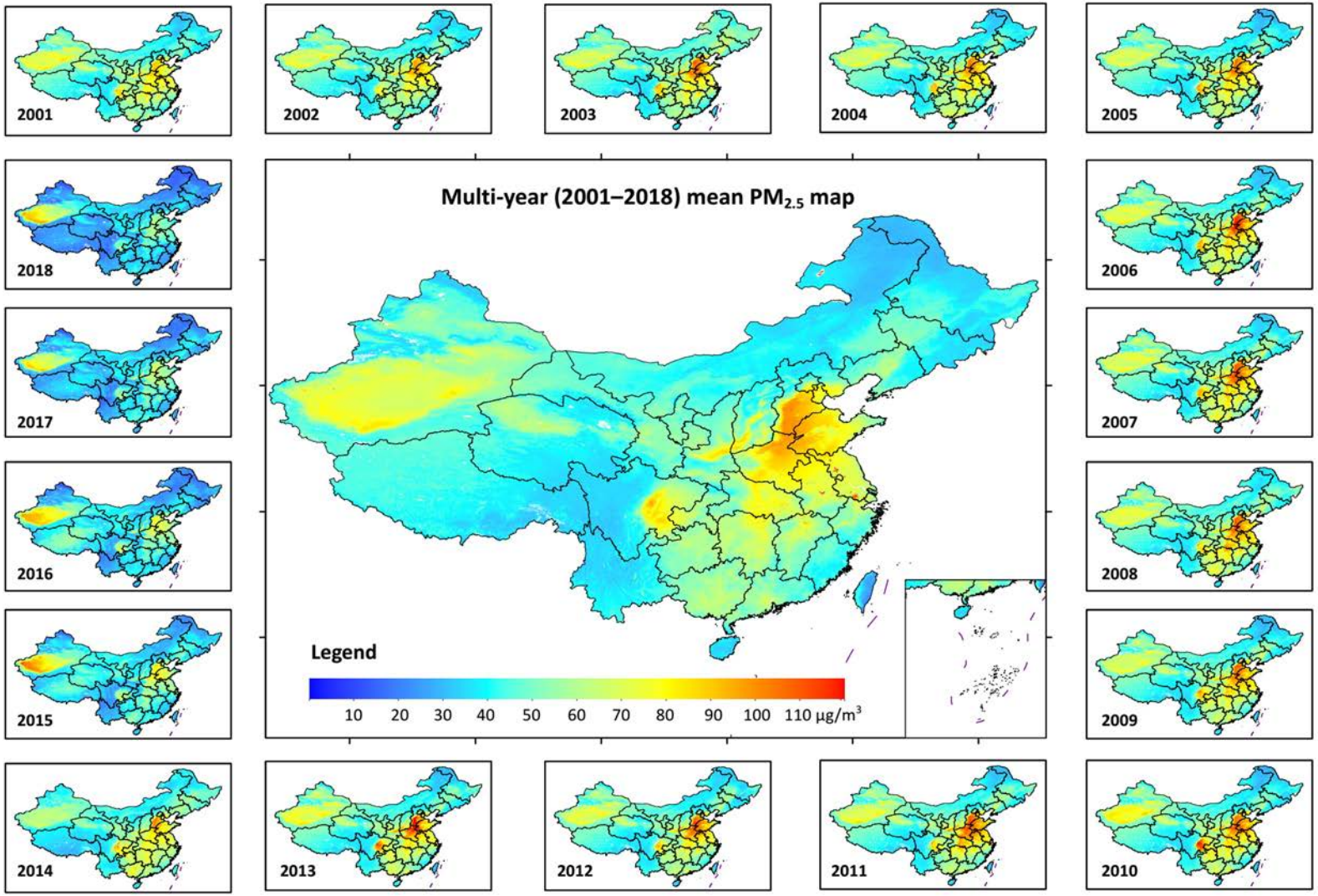
# Question I?

# How did $PM_{2.5}$ and its composition change across China during the last two decades?

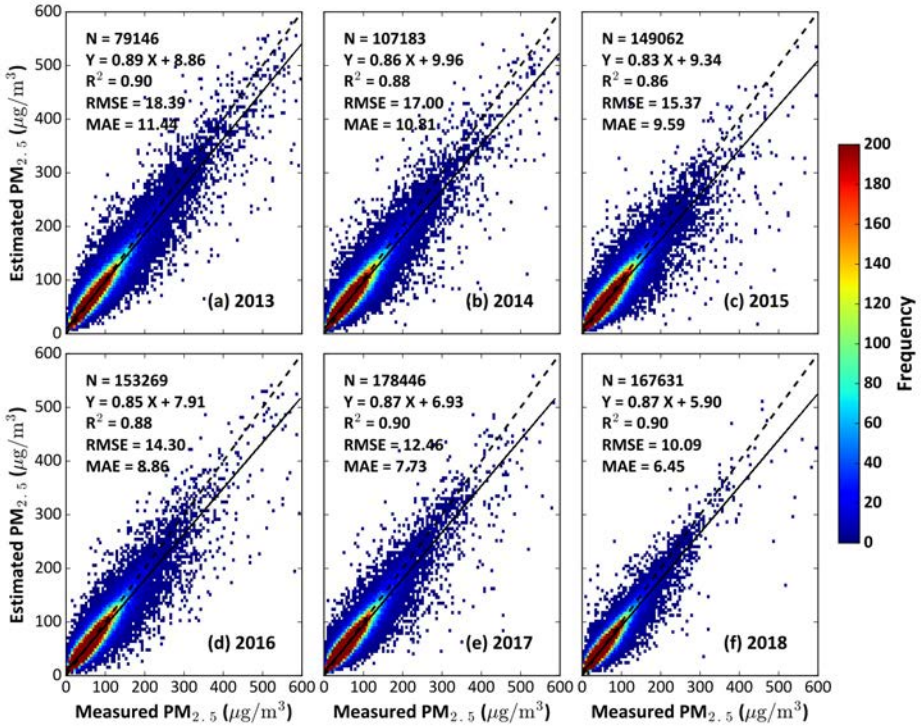
Thanks to more than 20 years of long-term earth observations by NASA MODIS, and its operational high-resolution AOD products, we have re-constructed **daily 1-km $PM_{2.5}$ data records from 2000 in China.** The long-term, continuous and seamless product allow objective evaluation of air quality change in time and space.

# MODIS-derived 20-years $PM_{2.5}$ records and validation

Using MODIS MAIAC AOD products, we reconstructed 1 km $PM_{2.5}$ data records since 2000 in China, making up for the gap in studies on long-term $PM_{2.5}$ variations since surface observations only date back to 2013.




## 10-fold cross-validation

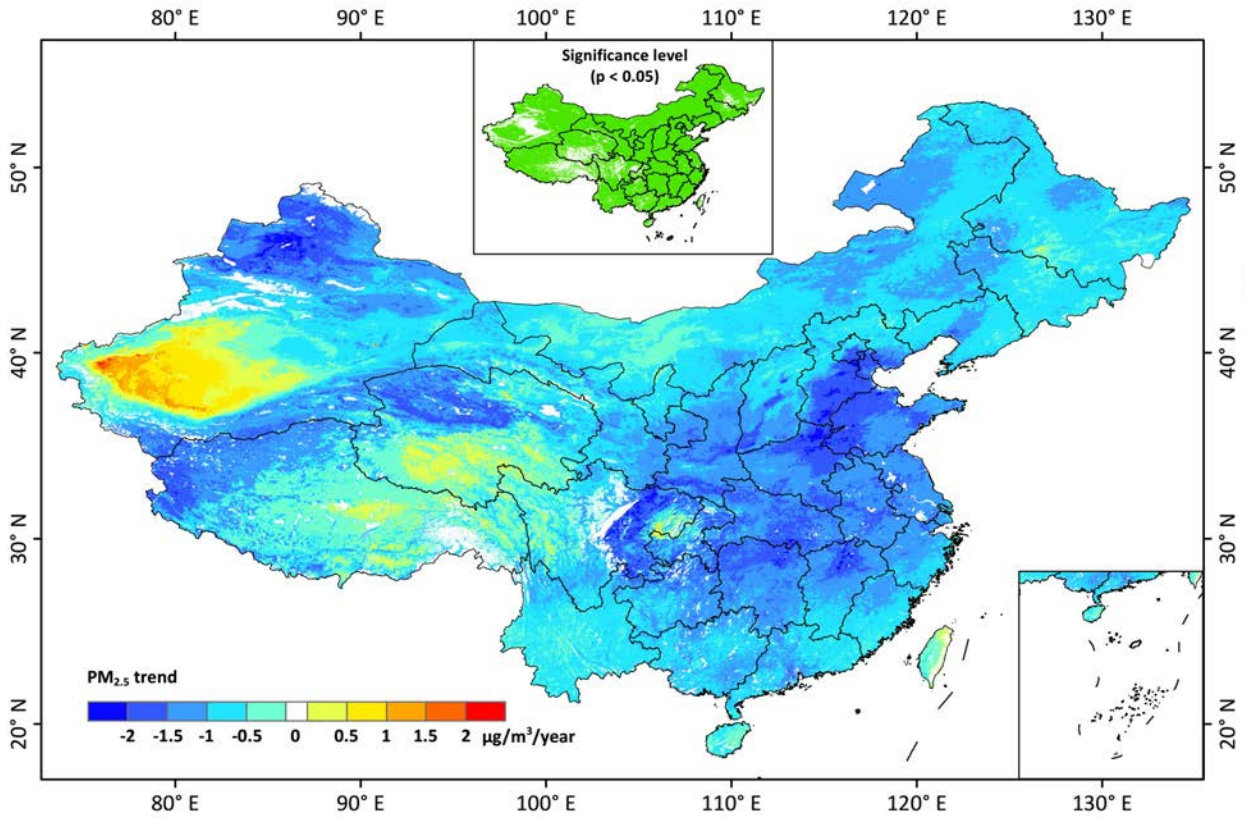



Daily $PM_{2.5}$ retrievals **agree well** with ground measurements among different years.

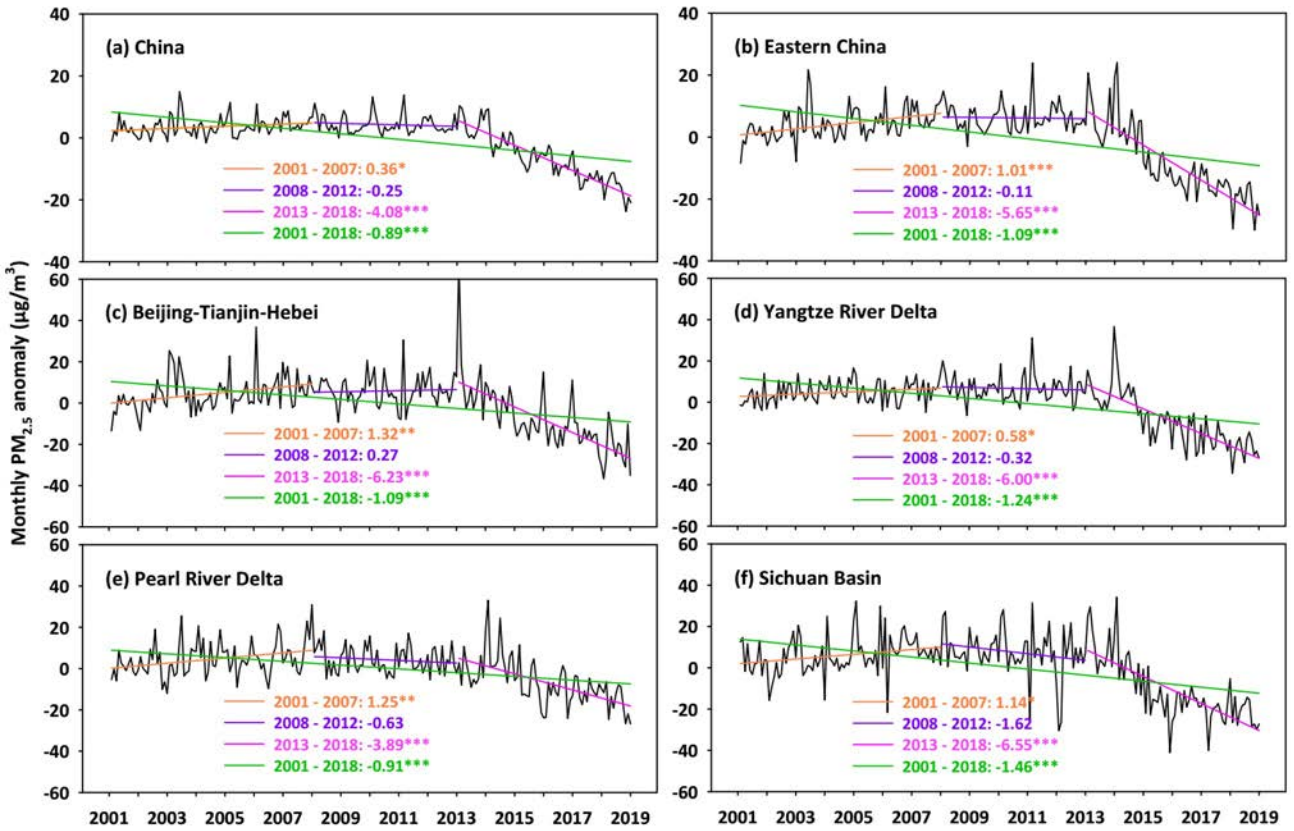
**Wei, Li, et al., *RSE*, 2021**

# Long-term temporal variations in $PM_{2.5}$ pollution

## Annual $PM_{2.5}$ trend during 2001-2018




## Monthly variations of $PM_{2.5}$ anomaly

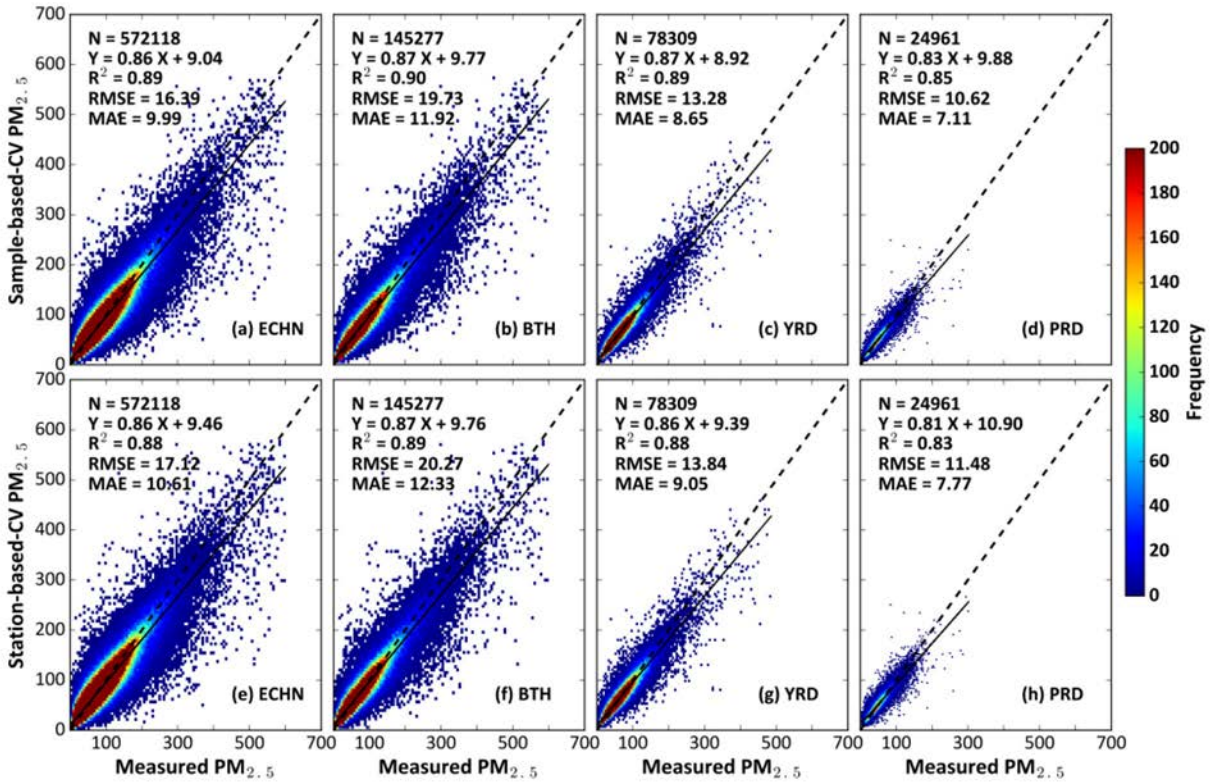



- $PM_{2.5}$ pollution has experienced dramatic changes: **increasing** until around 2007, **remaining high** until 2013, **and decreased significantly** since then in most areas especially in eastern China, in response to policy shift and economy-structure changes.

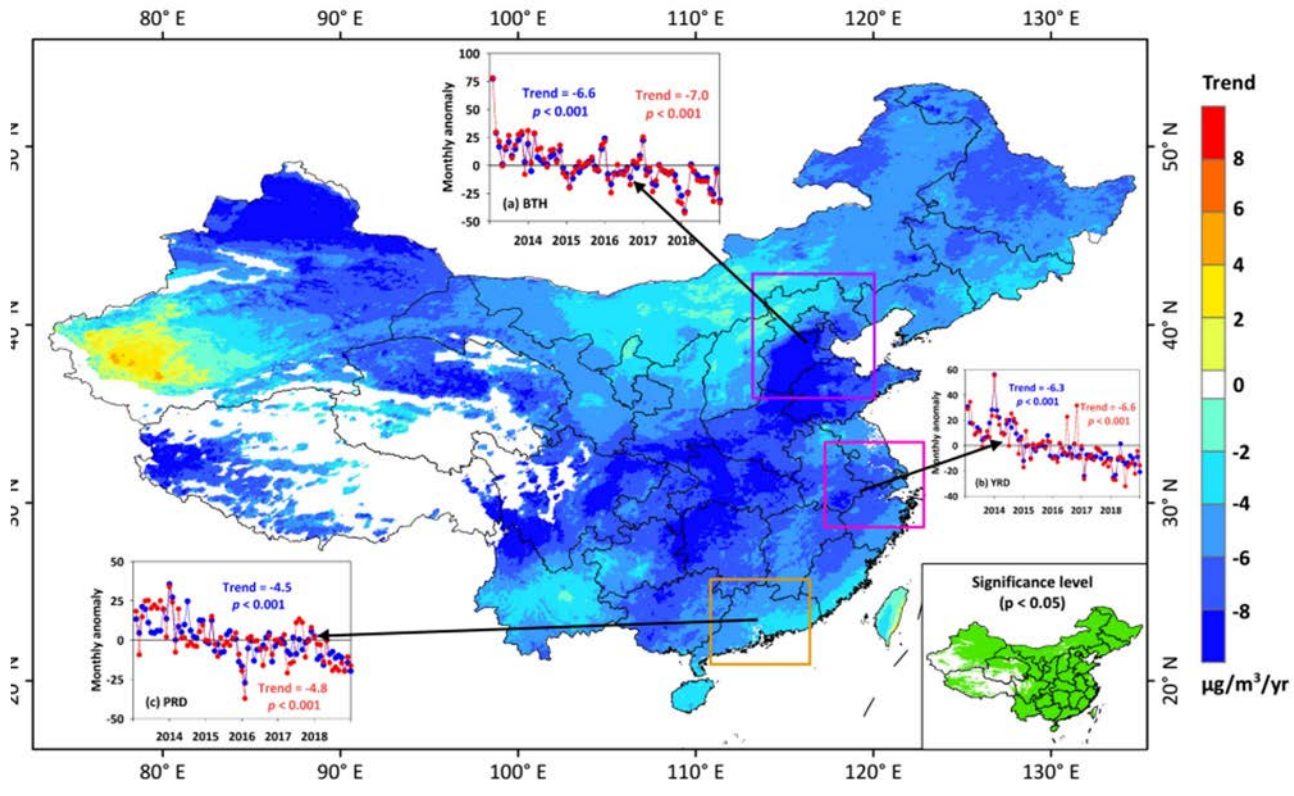
**Wei, Li, et al., *RSE*, 2021**

# Extending the EOS long-term $PM_{2.5}$ records with VIIRS AOD

## Validation of daily $PM_{2.5}$ estimates and predictions




## Temporal $PM_{2.5}$ trend since 2013

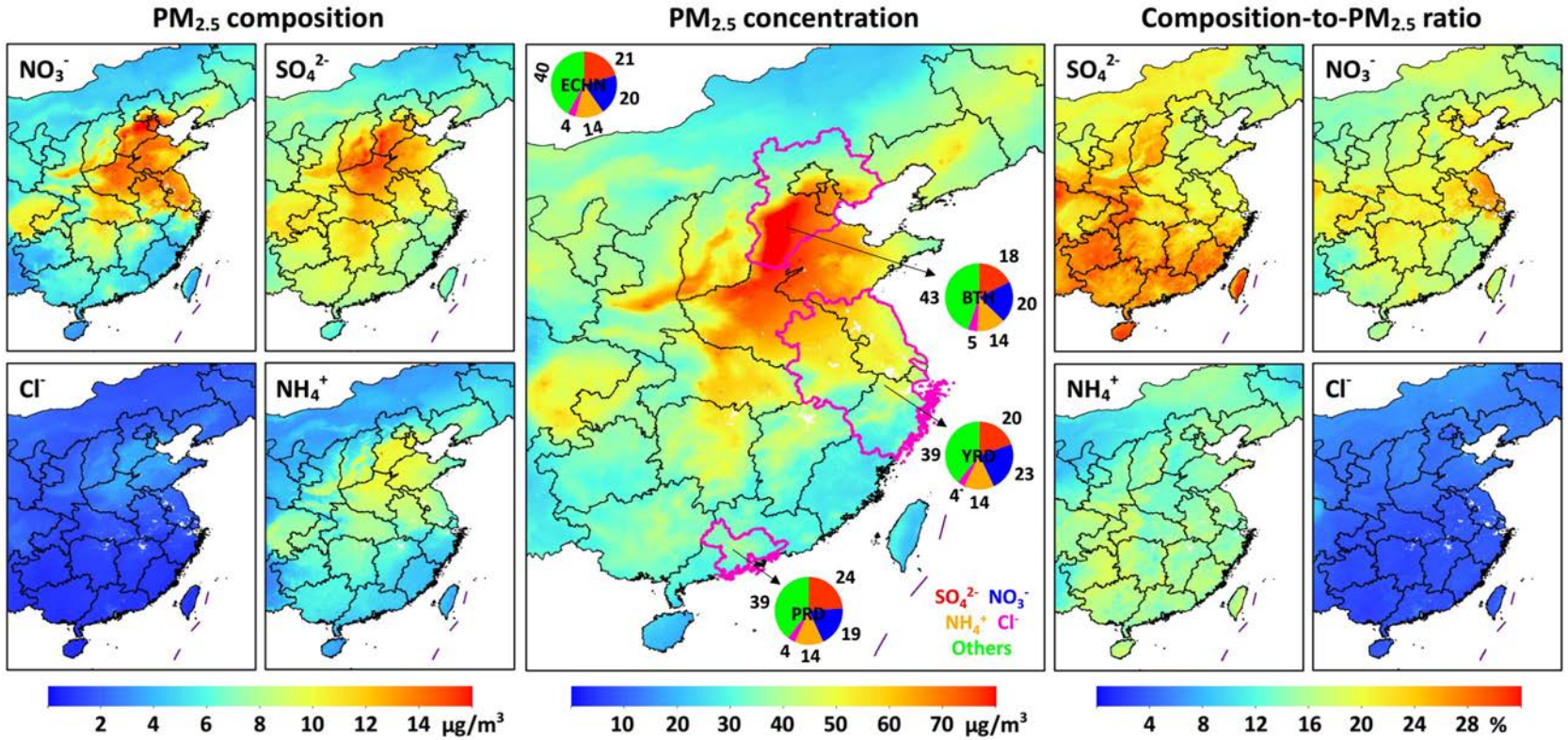



- Our $PM_{2.5}$ product has the unique advantages of the longest records, highest resolution, daily and seamless that can thus **well capture** the temporal trends and spatial inhomogeneity.
- VIIRS satellite aerosol products can be adopted to **extend** the Earth Observing System (EOS) long-term $PM_{2.5}$ data records using ML to the next few decades in the post MODIS/MISR era.

**Wei, Li, et al., *TGRS*, 2022**

# Separating $PM_{2.5}$ Chemical Composition via Deep Learning

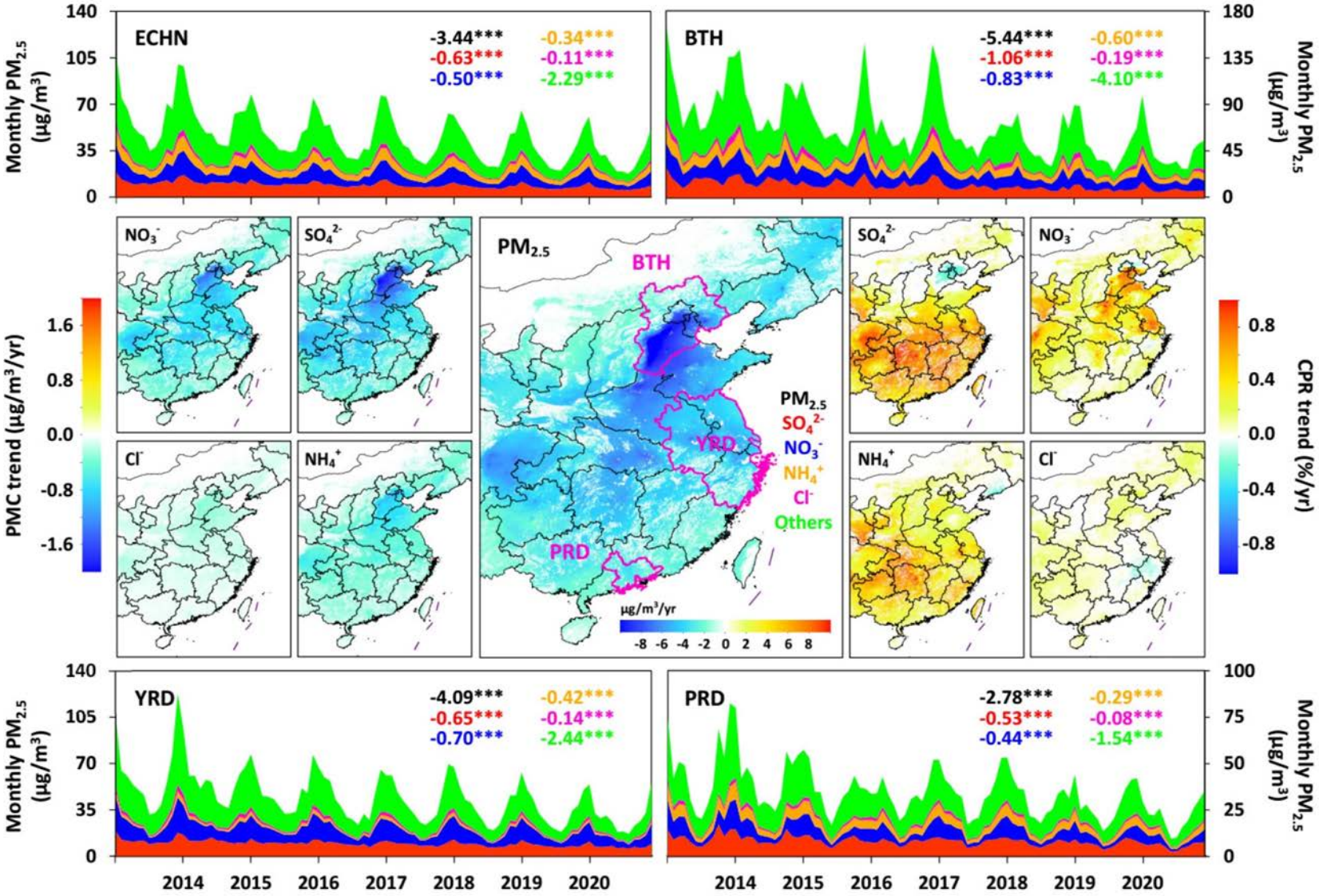
We developed a four-dimensional spatiotemporal deep forest (4D-STDF) model to estimate daily 1 km $PM_{2.5}$ chemical composition since 2000 from **a high-density observation network** and satellite $PM_{2.5}$ retrievals




- Cross-validation illustrates the reliability of sulfate ($SO_4^{2-}$), nitrate ($NO_3^-$), ammonium ($NH_4^+$), and chloride ($Cl^-$) estimates, with high CV-$R^2$ of 0.74, 0.75, 0.71, and 0.66, respectively, with reference to ground observations.
- Four main inorganic aerosols account for 58% of $PM_{2.5}$ in eastern China, and three SIA components account for 21% ($SO_4^{2-}$), 20% ($NO_3^-$), and 14% ($NH_4^+$) of the total $PM_{2.5}$ mass in eastern China.

**Wei, Li, et al., *EST*, 2022**

# Temporal Variation of Chemical Composition




**Trends of total $PM_{2.5}$ and components (PMC) and composition-to-$PM_{2.5}$ ratios (CPR) in eastern China from 2013 to 2020**

- We observed **significant reductions** in the mass of inorganic components by 40–43% between 2013 and 2020, slowing down since 2018.
- Comparatively, the ratio of SIA to $PM_{2.5}$ **increased** by 7% across eastern China except in Beijing and nearby areas, accelerating in recent years.
- $SO_4^{2-}$ has been the **dominant** SIA component in eastern China, although it was **surpassed** by $NO_3^-$ in some areas, e.g., Beijing–Tianjin–Hebei region since 2016.

**Wei, Li, et al., *EST*, 2023**

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

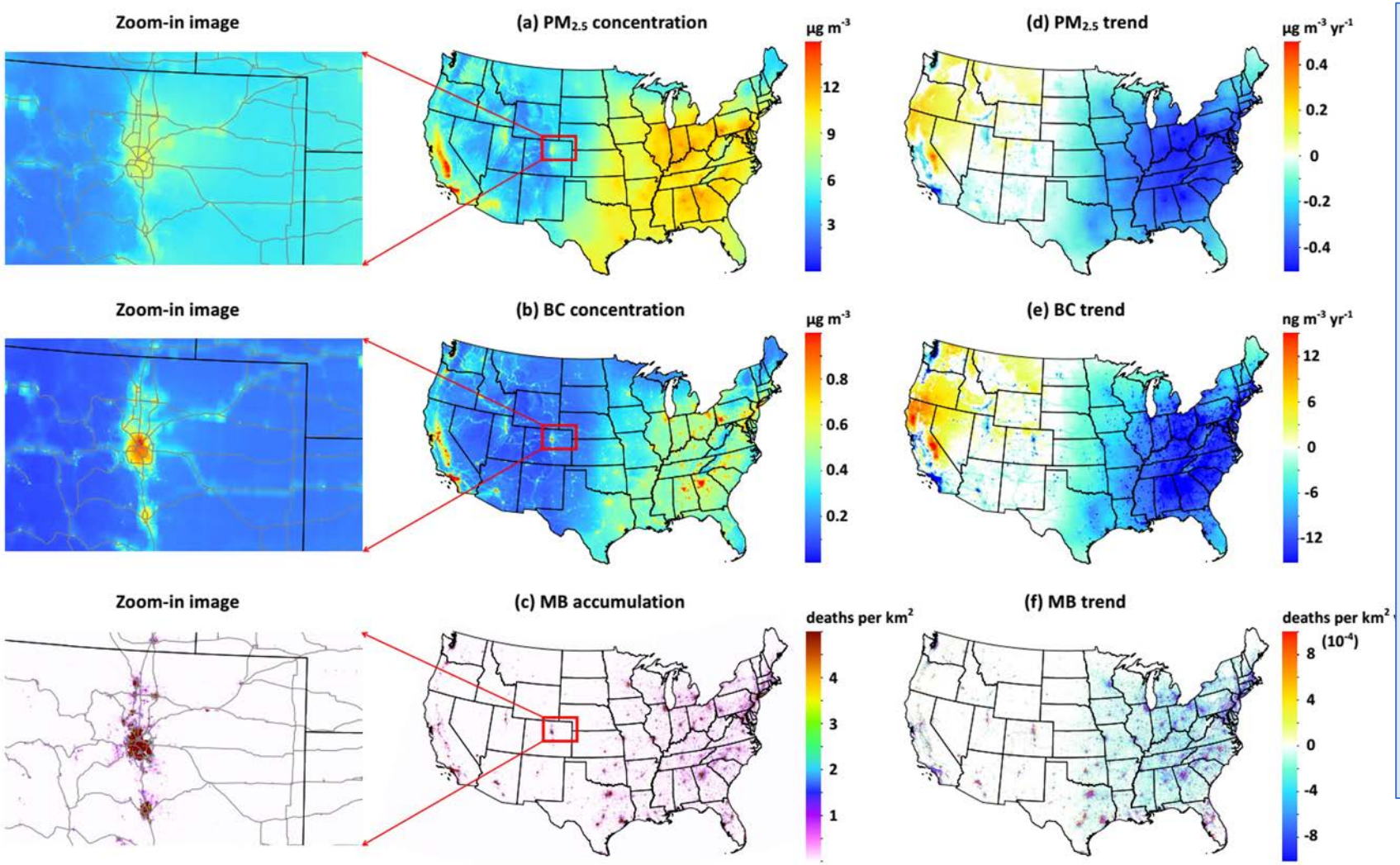
# Question II?

# How did the wildfires affect the long-term air quality and public health in the US?

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

# Spatiotemporal variations

## 2000 – 2020 Trends in $PM_{2.5}$, BC, and Mortality Burden

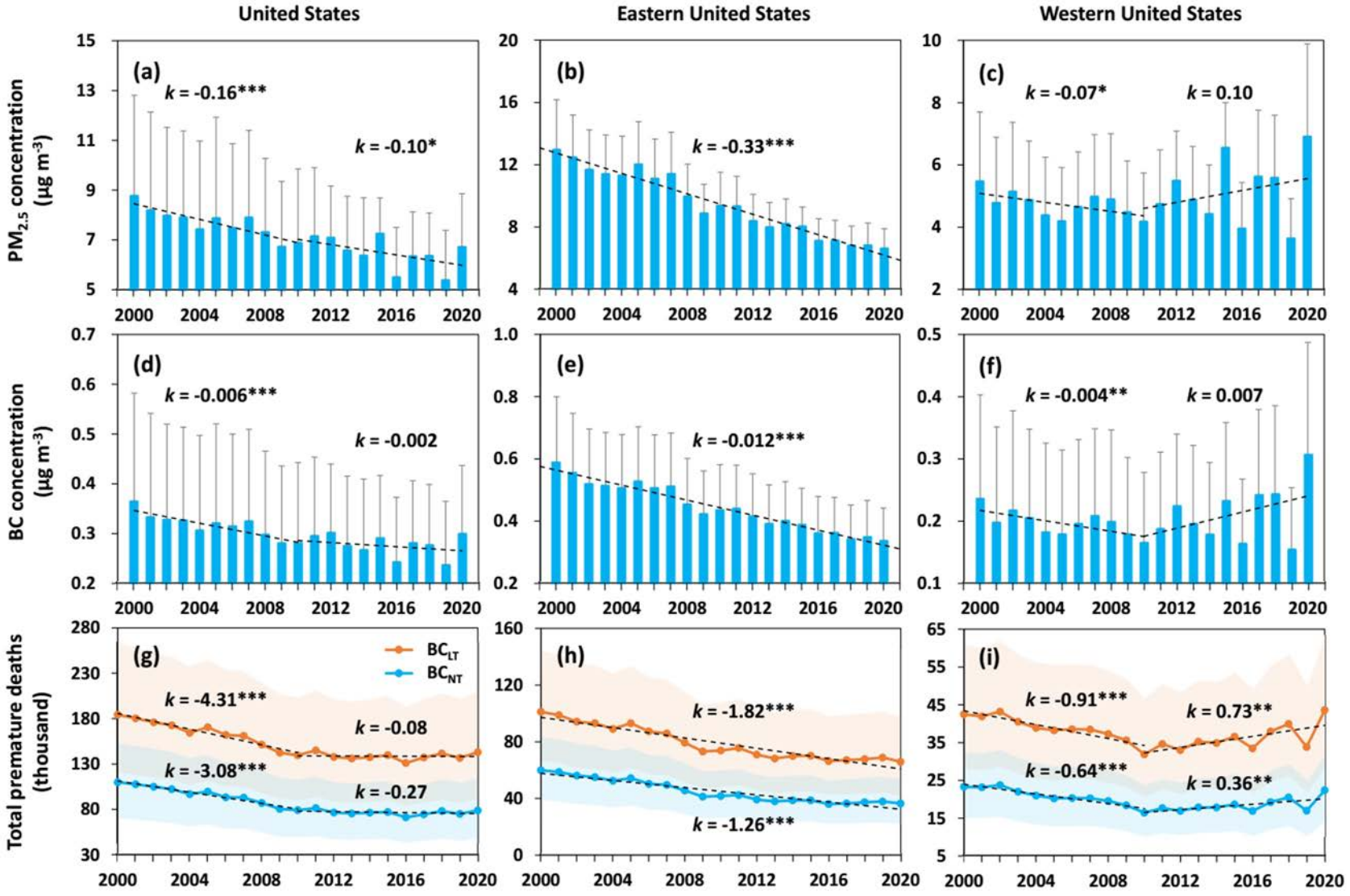



High BC concentrations along highways due to traffic-related emissions (from diesel trucks) are well captured.

- Annual $PM_{2.5}$ and BC have similar spatial distributions: US EAST are ~2 times **higher** than US WEST.
- Strong contrast in the air quality between urban and rural regions.
- Annual $PM_{2.5}$ and BC has **declined** steadily in the EAST, vs big **increases** in the WEST
- The opposite trends are seen in air quality related premature deaths: **increasing/decreasing** in the WEST and EAST.

**Wei et al., *Lancet – Planet Health*, under revision**

# Major findings and conclusions




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

- Nationally, the $PM_{2.5}$ and BC decreasing trends were **larger** in the first decade and **slowed down** after.
- Air quality has improved continuously in the EAST, whereas the same **downward** trend was **reversed** in the WEST due to increased fire emissions in the recent decade.
- And so are the trends in air quality-related mortality rate, e.g., an **increase** of ~730 (360) deaths per year in the WEST due to total and BC emissions.

**Wei et al., *Lancet – Planet Health*, under revision**

# Summary of the Air Quality Products

| ChinaHighAirPollutants (CHAP) | | | | | | |
|---|---|---|---|---|---|---|
| Air Pollutant | Main predictor | Spatial resolution | Seamless | Temporal resolution | Available period (yyyy/mm) | Access |
| $PM_1$ | MODIS | 1 km | Yes | Daily/Monthly/Yearly | 2000/01 – 2021/12 | Apply/Public |
| $PM_{2.5}$ | MODIS | 1 km | Yes | Daily/Monthly/Yearly | 2000/01 – 2021/12 | Public |
| | Himawari-8 | 5 km | No | Hourly | 2018/01 – 2018/12 | Public |
| $PM_{10}$ | MODIS | 1 km | Yes | Daily/Monthly/Yearly | 2000/01 – 2021/12 | Public |
| $O_3$ | Big data | 10 km | Yes | Daily/Monthly/Yearly | 1979/01 – 2020/12 | Public |
| | MODIS | 1 km | Yes | Daily/Monthly/Yearly | 2000/01 – 2021/12 | Apply |
| $NO_2$ | OMI | 10 km | Yes | Daily/Monthly/Yearly | 2008/01 – 2018/12 | Public |
| | TROPOMI | 1 km | Yes | Daily/Monthly/Yearly | 2019/01 – 2020/12 | Public |
| $SO_2$ | Big data | 10 km | Yes | Daily/Monthly/Yearly | 2013/01 – 2020/12 | Public |
| CO | Big data | 10 km | Yes | Daily/Monthly/Yearly | 2013/01 – 2020/12 | Public |
| $PM_{2.5}$ chemical composition | Big data | 1 km | Yes | Daily/Monthly/Yearly | 2000/01 – 2021/12 | Apply |
| Polycyclic aromatic hydrocarbons | Big data | 10 km | Yes | Daily/Monthly/Yearly | 2013/01 – 2021/12 | Apply |

# Online Products Distribution and Usage

Jing Wei | Chinese

HOME | PUBLICATION | PRESENTATION | RESEARCH | PRODUCT | NEWS

**GitHub**

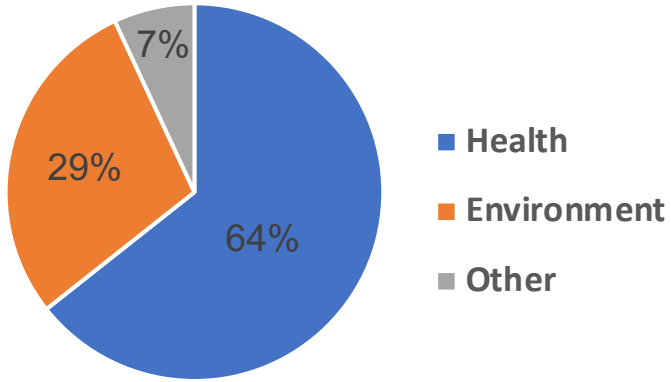
## ChinaHighAirPollutants (CHAP)

New update: Daily seamless 1 km $PM_x$ and composition data released!

- **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**), and **$PM_{2.5}$ chemical compositions (e.g., $SO_4^{2-}$, $NO_3^-$, $NH_4^+$, $Cl^-$, and BC, et al.)**. This CHAP dataset is **public** and **freely** open to all users!

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




Published > **160** applied papers in leading journals like *Thorax*, *Hypertension*, *ES&T*, *GRL*, *et al.!*

The air quality datasets have been widely used in environmental health studies, among others, leading to **hundreds** of publications

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November 12, 2019 | Dataset | Open Access

### ChinaHighPM2.5: Big Data Seamless 1 km Ground-level PM2.5 Dataset for China

Jing Wei, Zhanqing Li

ChinaHighPM$_{2.5}$ is one of the series of long-term, full-coverage, high-resolution, and high-quality datasets of ground-level air pollutants for China (i.e., ChinaHighAirPollutants, CHAP). 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.

This is the big data-derived seamless (spatial coverage = 100%) daily, monthly, and yearly 1 km (i.e., D1K, M1K, and Y1K) ground-level PM$_{2.5}$ dataset in China from 2000 to 2021. This dataset yields a high quality with a cross-validation coefficient of determination (CV-$R^2$) of 0.92 and a root-mean-square error (RMSE) of 10.76 μg $m^{-3}$ on a daily basis.

If you use the ChinaHighPM$_{2.5}$ dataset for related scientific research, please cite the below-listed corresponding references first (Wei et al., RSE, 2021; Wei et al., ACP, 2020), and the reference will be updated once our new paper is accepted.

[1] Wei, J., Li, Z., Lyapustin, A., Sun, L., Peng, Y., Xue, W., Su, T., and Cribb, M. 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. https://doi.org/10.1016/j.rse.2020.112136

[2] Wei, J., Li, Z., Cribb, M., Huang, W., Xue, W., Sun, L., Guo, J., Peng, Y., Li, J., Lyapustin, A., Liu, L., Wu, H., and Song, Y. Improved 1 km resolution PM$_{2.5}$ estimates across China using enhanced space-time extremely randomized trees, *Atmospheric Chemistry and Physics*, 2020, 20(6), 3273-3289. https://doi.org/10.5194/acp-20-3273-2020

**More CHAP datasets of different air pollutants can be found at: https://weijing-rs.github.io/product.html**

| | 19,953 views | 101,032 downloads |
|---|---|---|
| | All versions | This version |
| Views | 19,953 | 6,251 |
| Downloads | 101,032 | 59,798 |
| Data volume | 123.4 TB | 121.2 TB |
| Unique views | 14,065 | 4,623 |
| Unique downloads | 16,136 | 7,952 |

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https://doi.org/10.5281/zenodo.3539349

# Related Publications and Citations

- **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, Journal Most Cited Articles since 2019 and 2020) [281]**
- **Wei, J., Li, Z.***, 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) [236]**
- **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) [154]**
- **Wei, J.***, **Li, Z.***, et al. Separating daily 1 km $PM_{2.5}$ inorganic chemical composition in China since 2000 via deep learning integrating ground, satellite, and model data. *Environmental Science & Technology*, 2023, in press.
- **Wei, J.***, **Li, Z.***, et al. Extending the EOS long-term $PM_{2.5}$ data records since 2013 in China: application to the VIIRS Deep Blue aerosol products. *IEEE Transactions on Geoscience and Remote Sensing*, 2022, 60, 4100412.
- **Wei, J.***, Wang, J., **Li, Z.**, et al. Wildfire emissions disrupt black carbon and $PM_{2.5}$ mortality burden trends across the continental US. *The Lancet – Planetary Health,* 2022, under revision.

THANKS