Advancing Satellite-Derived $PM_{2.5}$ to Support the Health and Air Quality Management Communities

Randall Martin

with contributions from

Nidhi Anchan, Chi Li, Christopher Oxford, Yuxuan Ren, Siyuan Shen, Aaron van Donkelaar, Dandan Zhang, Bill Zhuge

WashU

ACAG

Michael Brauer (UBC), Alex de Sherbinin (U Columbia), Michael Garay (JPL), Christina Hsu (NASA), Olga Kalashnikova (JPL), Ralph Kahn (CU Boulder), Dohyung Kim (UNICEF), Shobha Kondragunta (NOAA), Robert Levy (NASA), Alexei Lyapustin (NASA), Pallavi Pant (HEI), Yinon Rudich (Weizmann), Andrew Sayer (NASA), John Voorheis (US Census Bureau)

HAQAST St Louis
WashU
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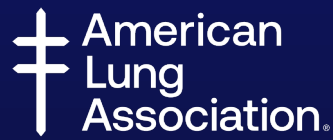
Large Community Requires Information on Distribution of $PM_{2.5}$



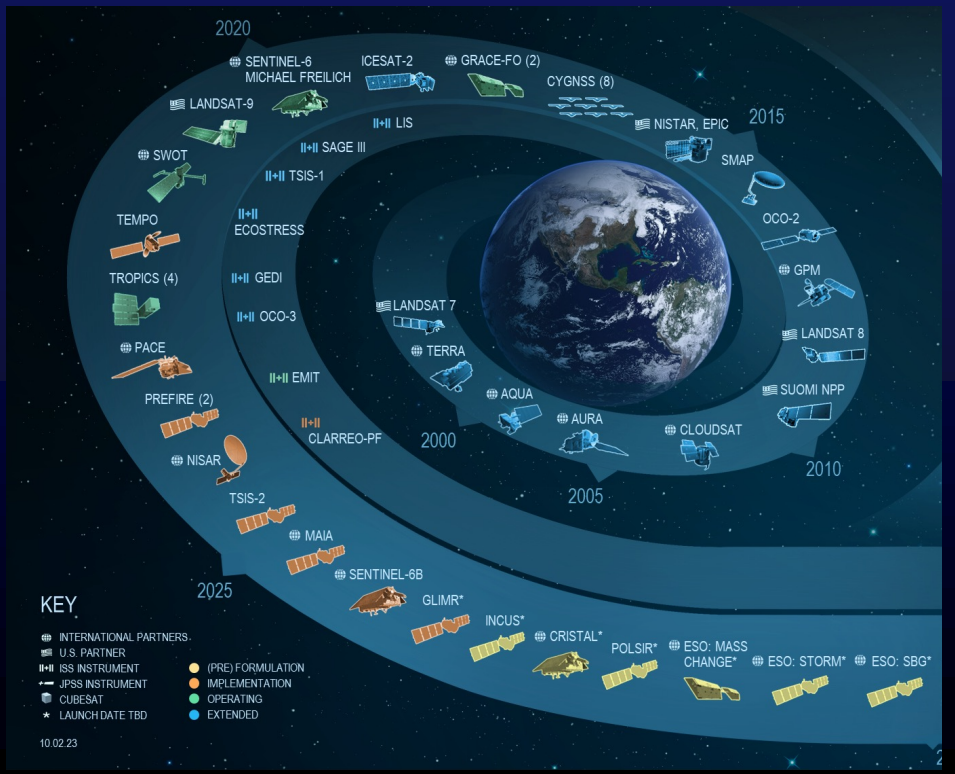
Epidemiological studies

Use Satellite Observations as Primary Data Source
Motivated by Large Gaps in Ground-Based Monitoring

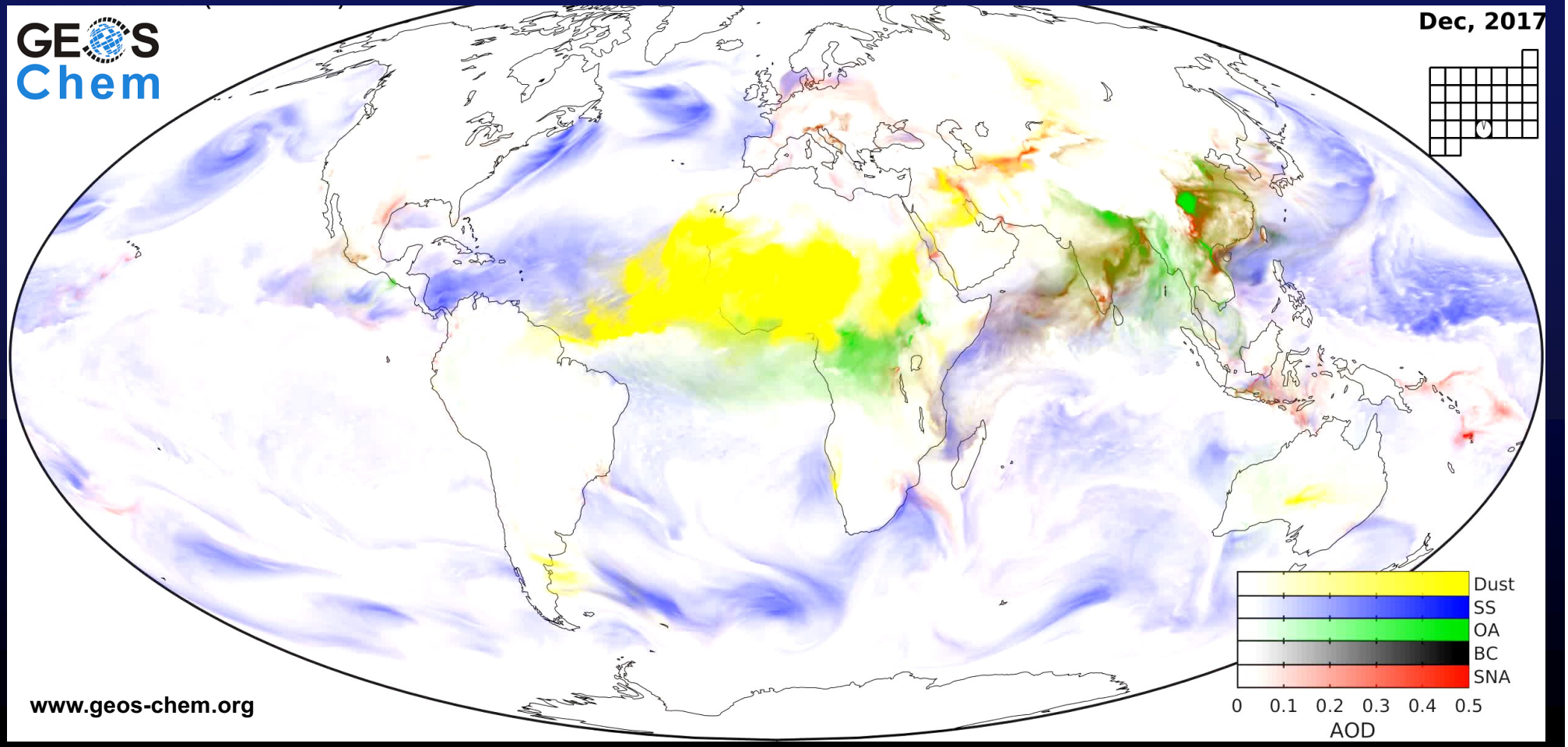
Instruments: MODIS-Terra, MODIS-Aqua, VIIRS-SNPP, VIIRS-NOAA20, MISR, SeaWiFS

Algorithms: MAIAC, Deep Blue, Dark Target, MISR

Large and growing constellation of observations



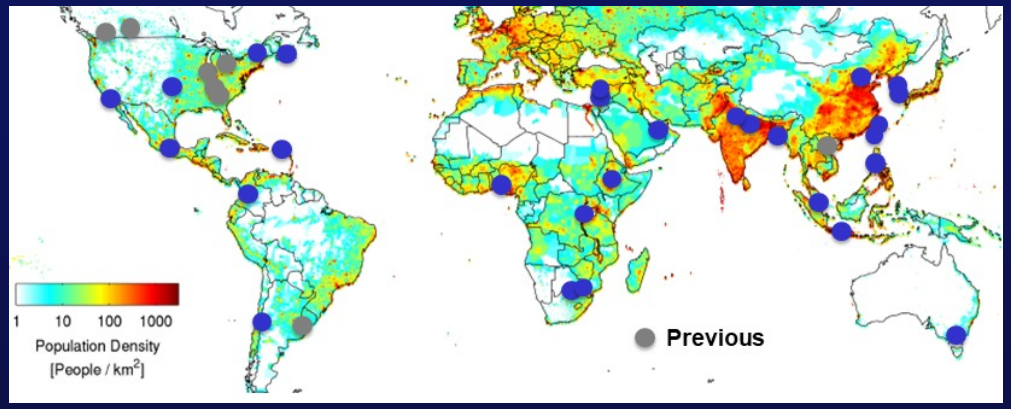
Apply Chemical Transport Model (GEOS-Chem) to Calculate Spatially- and Temporally-Varying Relationship of AOD with $PM_{2.5}$

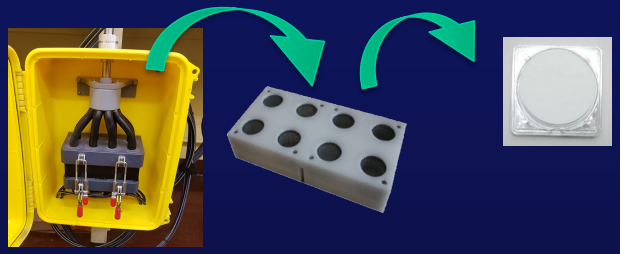


Simulation on NASA Pleiades supercomputer

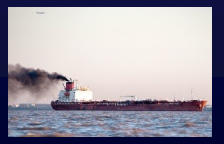
Dandan Zhang

A Growing Harmonized Air Quality Network: Surface Particulate Matter Network (SPARTAN)

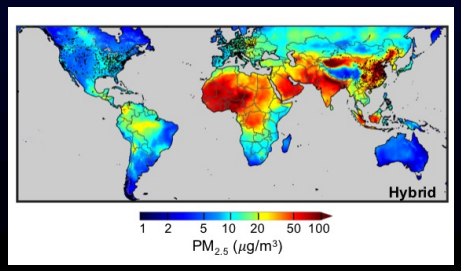




Global $PM_{2.5}$ composition network: offers information about sources



Supporting satellite-based $PM_{2.5}$ inference



SPARTAN
Global Particulate Matter Network

Overall operations led by Chris Oxford

www.spartan-network.org

Supported by Yuxuan Ren, Nidhi Anchan, Ryan Graham, Kamlendra Pathak, Will Frohling

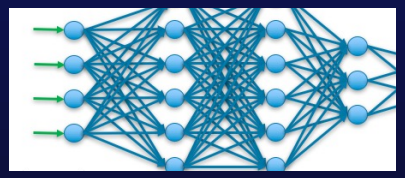
Deep Learning With Geophysical A Priori Information

Aerosol Optical Depth (AOD) from multiple satellite instruments and algorithms constrained with AERONET

Calculate coincident local solution to $PM_{2.5} = f(x,y,t,AOD)$

GEOS Chem

Geophysical Satellite-Derived $PM_{2.5}$



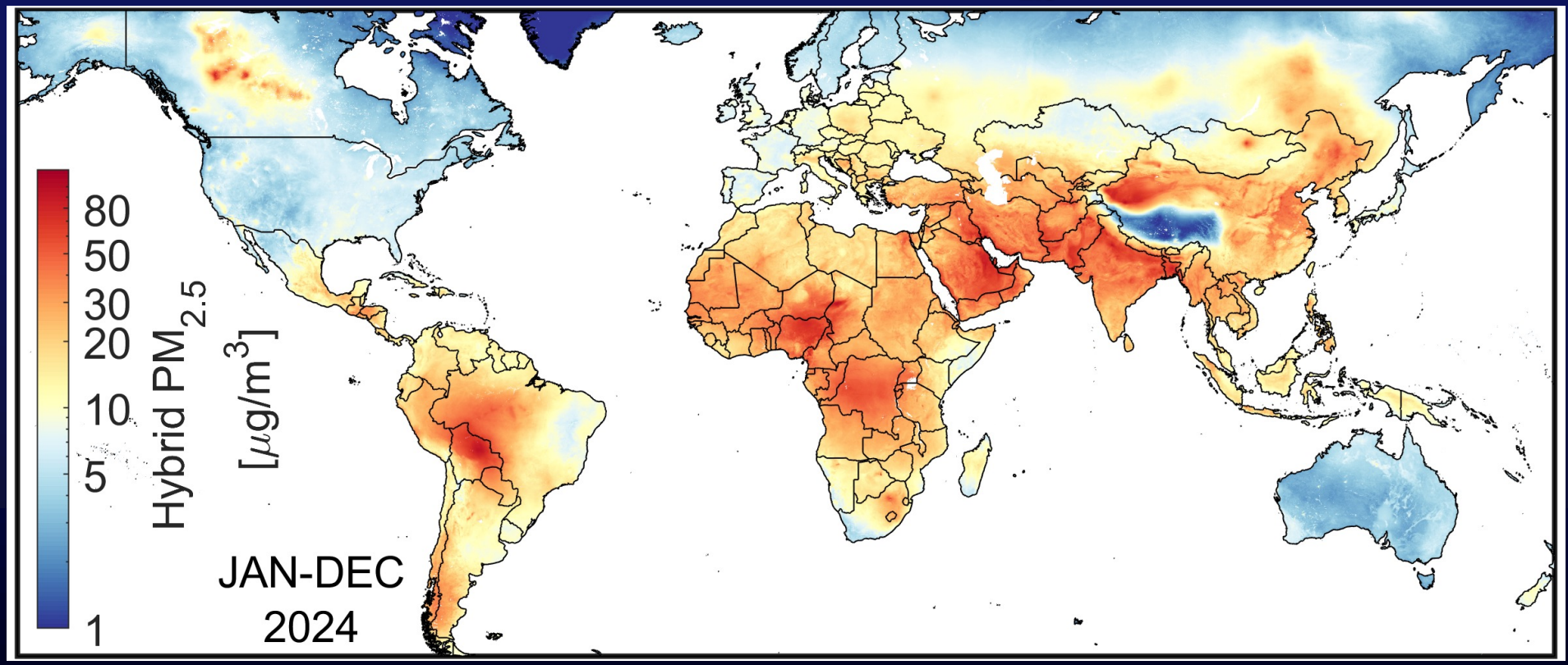
Deep Learning

Monitoring networks

Hybrid $PM_{2.5}$ Estimates

Shen et al., 2024

27-Year Record of Satellite-Derived $PM_{2.5}$ (1998-2024)



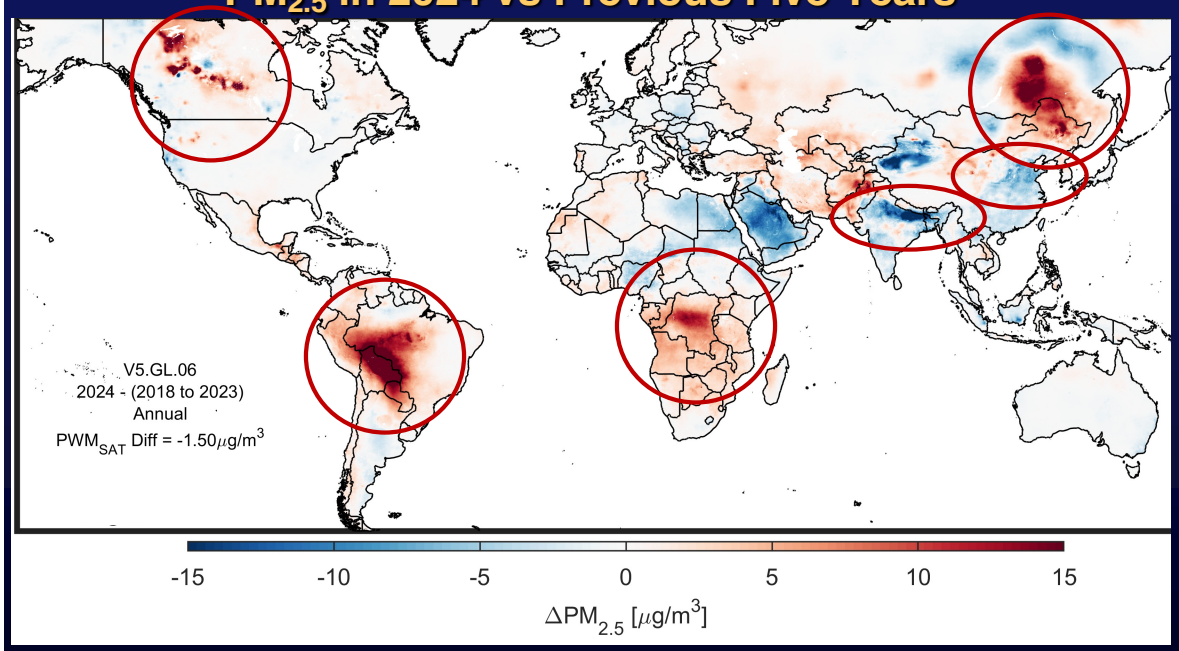
World Health Organization global annual mean $PM_{2.5}$ guideline: 5 ug/m^3

Information source for

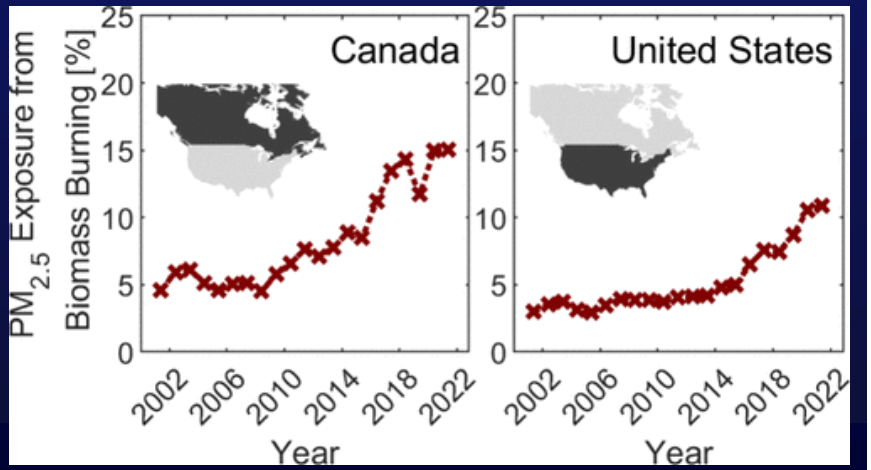
- Global Burden of Disease
- OECD Regional Well Being Index
- World Health Organization
- UN Development Program
- HEI State of Global Air
- Air Quality Life Index
- World Bank
- UNICEF
- Environmental Performance Index
- Environmental Systems Research Institute (ESRI)

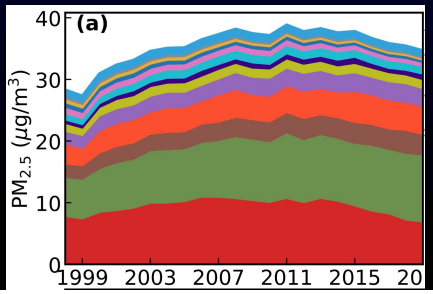
Continuation of Two Major $PM_{2.5}$ Trends: Decreasing Global Burden and Increasing Wildfire Contribution

$PM_{2.5}$ in 2024 vs Previous Five Years



Growing Fire Contribution to $PM_{2.5}$



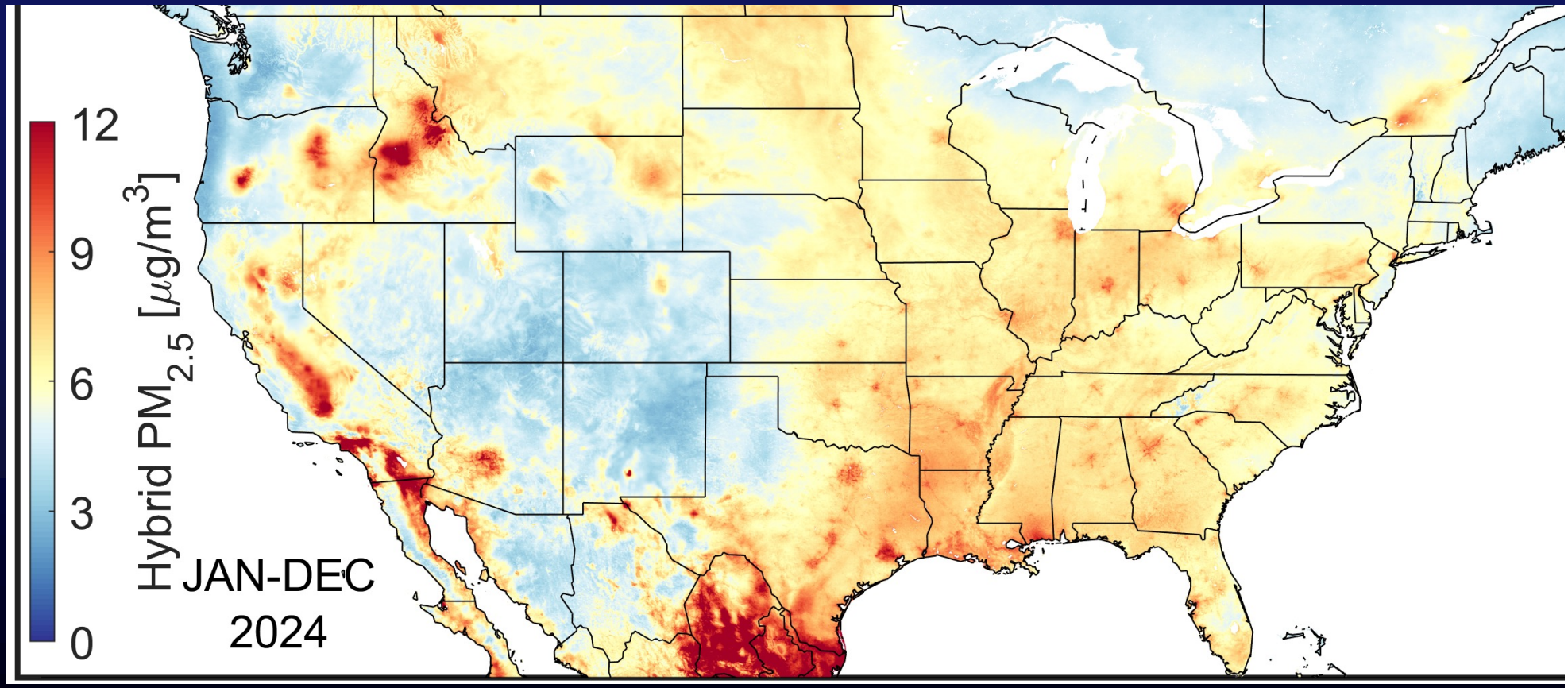


Reversal in Global $PM_{2.5}$ Burden
Li et al., Nat. Comm., 2023

Biomass burning contribution determined by sensitivity simulations using GEOS-Chem model

van Donkelaar et al., ES&T Air, 2024

27-Year Record of Satellite-Derived $PM_{2.5}$ (1998-2024)



US annual mean $PM_{2.5}$ standard: 9 ug/m^3

Information source for

- EPA Science Assessments
- American Lung Association State of the Air
- US Census Bureau
- Epidemiological studies

Learning about Association with Health Outcomes through Epidemiological Studies

Benefits from Large Statistical Power

- Asthma (Anenberg et al., EHP, 2018; Lavigne et al. 2019)
- Cardiovascular disease (Bai et al., Epidemiology, 2024; Bai et al., JAHA 2022; Liang et al., 2022; Kim et al., STOTEN, 2024)
- Childhood cancer (Lavigne et al., Env Int, 2017) & breast cancer (Bai et al. 2019)
- Cognitive development in children (Odo et al., Environ. Poll., 2023)
- COVID-19 outcomes (Bowe et al., Env. Int., 2021; Chakrabarty et al., STOTEN, 2020; Chen et al.,CMAJ,2022)
- Dementia (Ilango et al., IJ Epi, 2019, Li et al., Innovation, 2022; Shi et al., PNAS, 2023)
- Diabetes incidence (Bai et al., Epidemiol., 2019; Elten et al., Environ. Res., 2021)
- Diabetes mortality (Paul et al., Env. Int., 2019)
- Heart attack and stroke (Olaniyan et al., Env. Research, 2022)
- Lung cancer (Tomczak et al., IJC, 2016; Hystad et al., Env. Health, 2012)
- Pregnancy & birth outcomes (Lavigne et al. 2019; Johnson et al., Epidemiology, 2022)
- Respiratory infection in children (Odo et al., Env. Int., 2022)
- Shape of exposure-response function at low $PM_{2.5}$ concentrations (Pinault et al., Env. Res., 2017; Burnett et al., PNAS, 2018; Weichenthal et al., Science Adv., 2022)

Contributed to evidence supporting lowering of WHO annual $PM_{2.5}$ guideline and US EPA annual $PM_{2.5}$ standard

Plans

- Include recent and forthcoming advances
  - in satellite observations (e.g., PACE, MAIA, TEMPO)
  - in GEOS-Chem (e.g., GEOS-Chem High Performance)
  - in deep learning (e.g., CNN and random forests accounting for autocorrelation)
  - in ground-based measurements (e.g., SPARTAN)

- Support users with a dedicated user-support team (www.satpm.org)

- Collaborate extensively across the HAQAST community

Posters:

Diurnal variation of $PM_{2.5}$: Yanshun Li
Evaluation of black carbon emissions: Yuxuan Ren
Deep learning for $PM_{2.5}$ chemical composition: Siyuan Shen
Long-term trends in $PM_{2.5}$ chemical composition: Yuanjian Zhang
Is your county's $PM_{2.5}$ monitor capturing peak concentration? Chandler Wells (Holloway group)

Conclusions

- Utility of $PM_{2.5}$ concentrations inferred from satellite remote sensing, chemical transport modeling, deep learning, and ground-based measurements
- Data supports national and international assessments
- Ongoing need to evaluate and improve these data to inform air quality management in the context of societal and environmental change