Personalizing Air Pollution Exposure Science to Advance Precision Environmental Health

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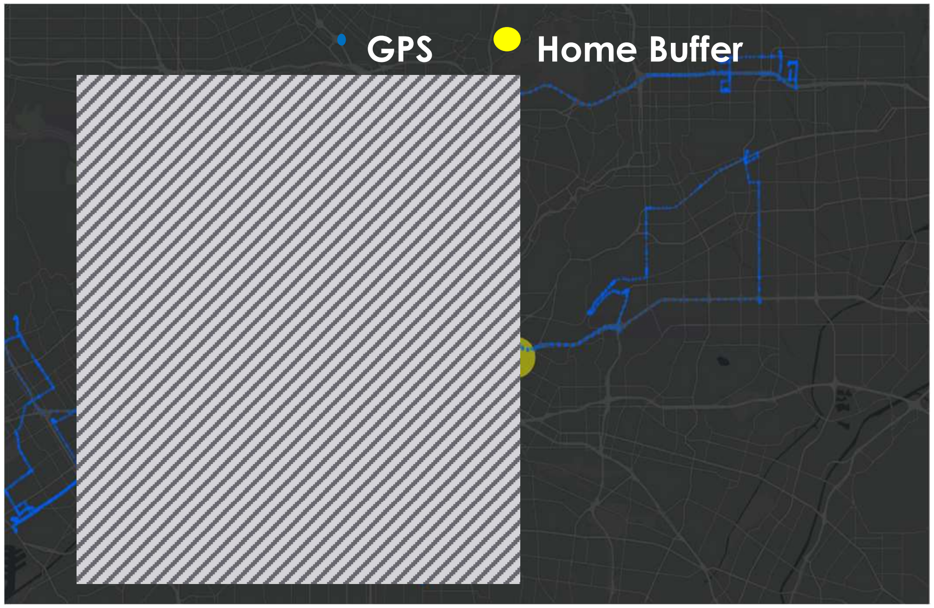
Motivation

- Air pollution is the largest environmental risk factor in the global burden of disease
  - Systemic inequities leading to persistent environmental health disparities
  - Climate change contributing to worsening air quality, wildfires, and widening disparities
- Personal exposure is complex
  - Mixtures from various sources – varying physicochemical properties and toxicity
  - Human mobility, time-activity patterns, behaviors often ignored → exposure measurement error
- Recent advances increasing our ability to personalize exposure
- Advance precision environmental health, design targeted interventions, and reduce health disparities

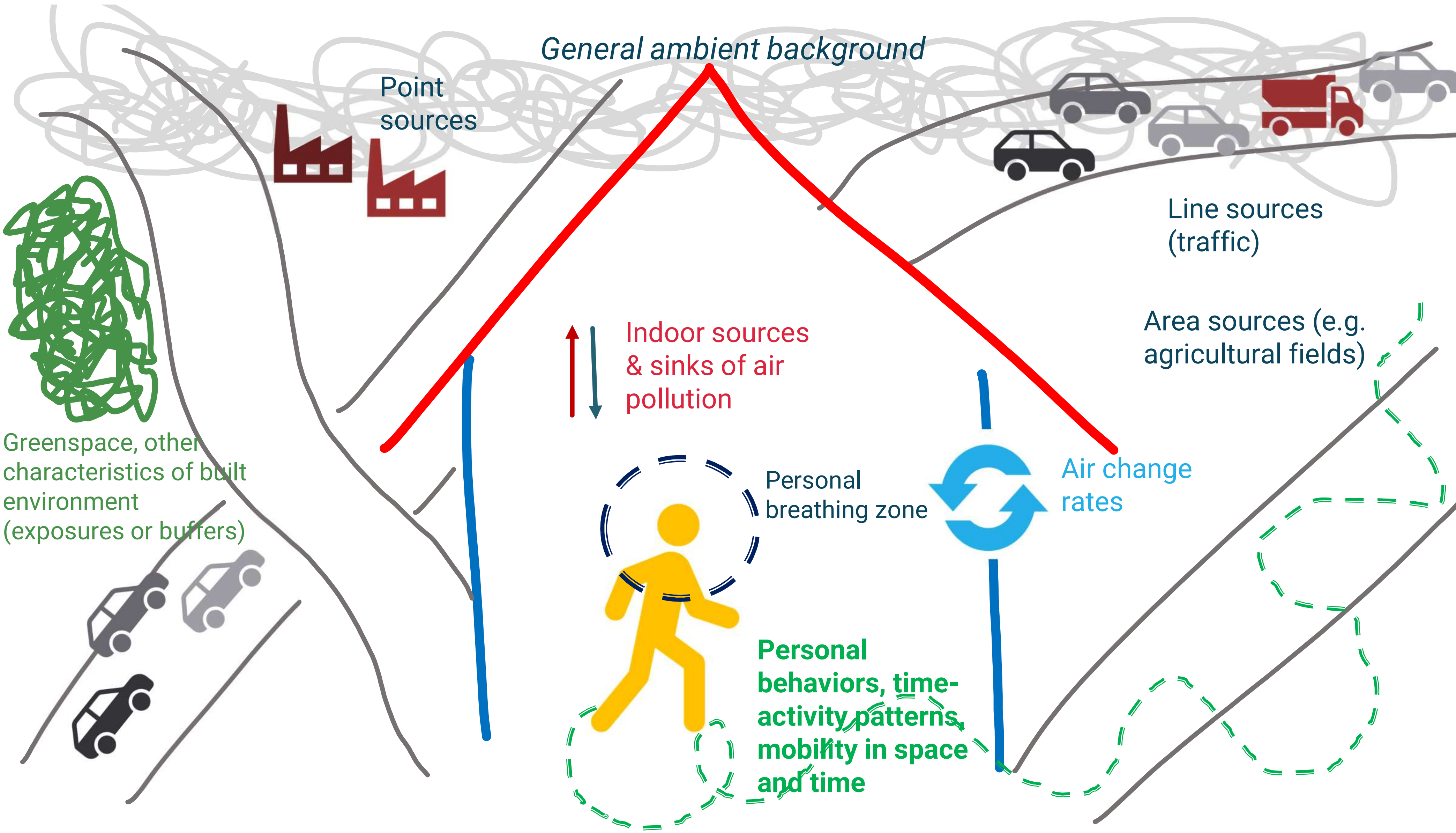
Illustrating the Problem

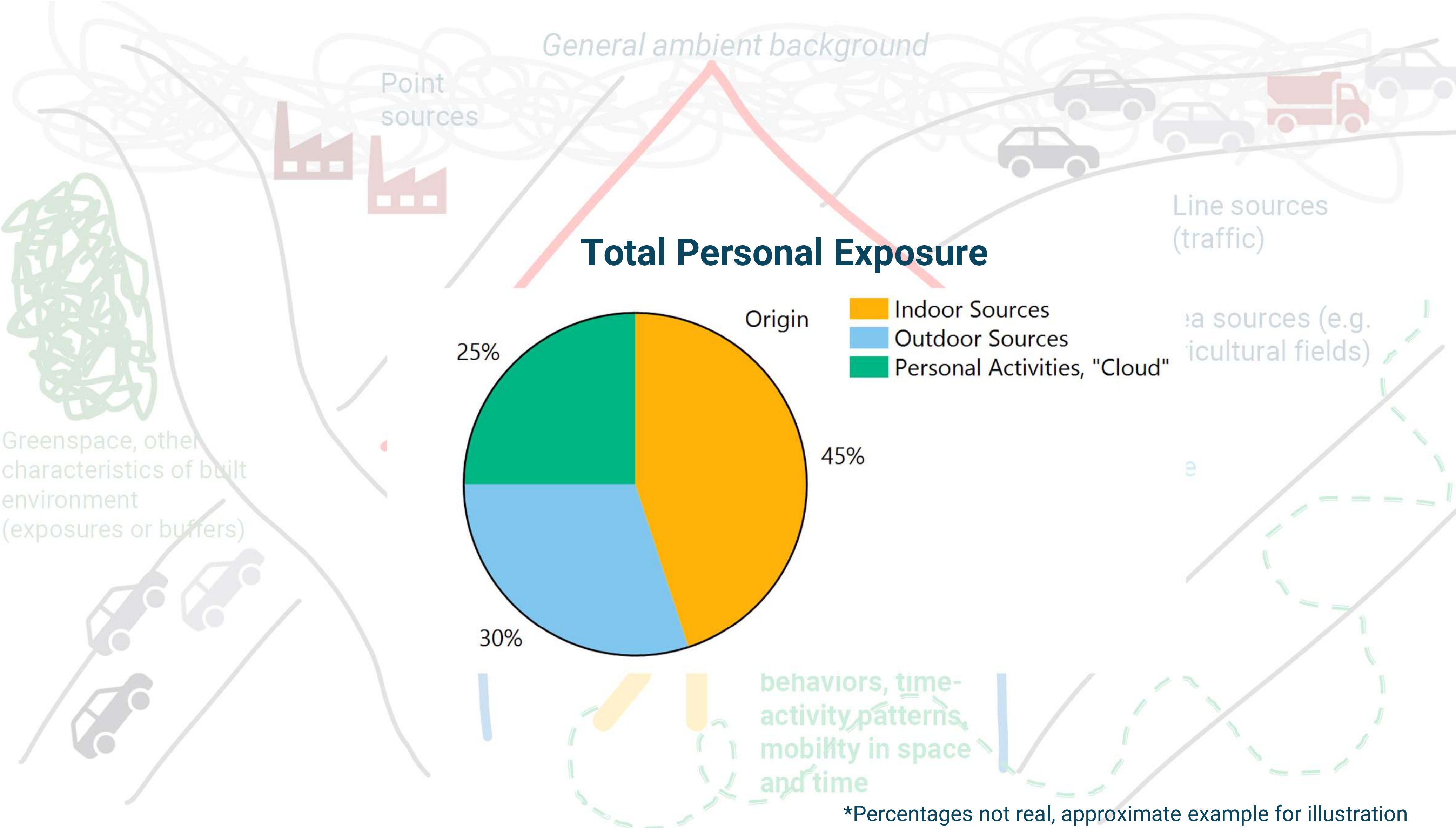


Assessing exposure at the residential neighborhood ignores exposures encountered within actual activity spaces

Li Yi, PhD

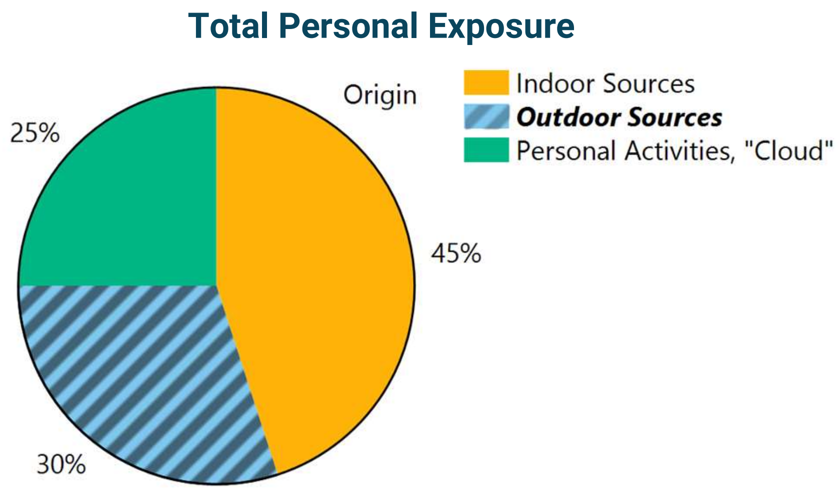
What Determines Personal Exposure?


General ambient background
Point sources
Line sources (traffic)
Area sources (e.g. agricultural fields)
Greenspace, other characteristics of built environment (exposures or buffers)
Indoor sources & sinks of air pollution
Personal breathing zone
Air change rates
Personal behaviors, time-activity patterns, mobility in space and time



*Percentages not real, approximate example for illustration

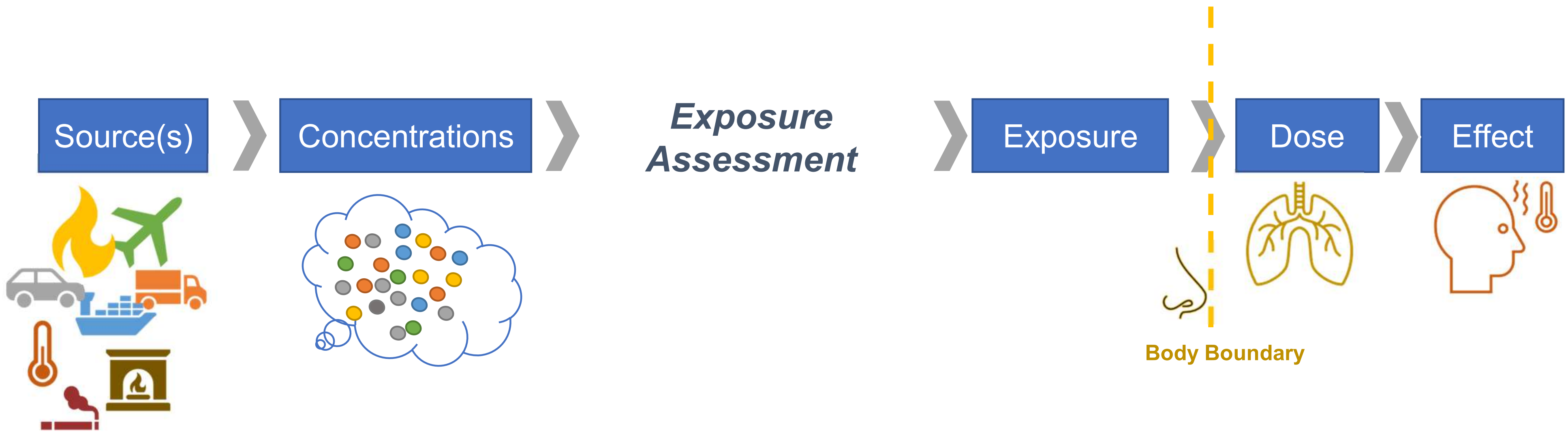
What Is Often Not Clearly Described



Studies of *outdoor* air pollution are often interested in this slice…

*Percentages not real, approximate example for illustration

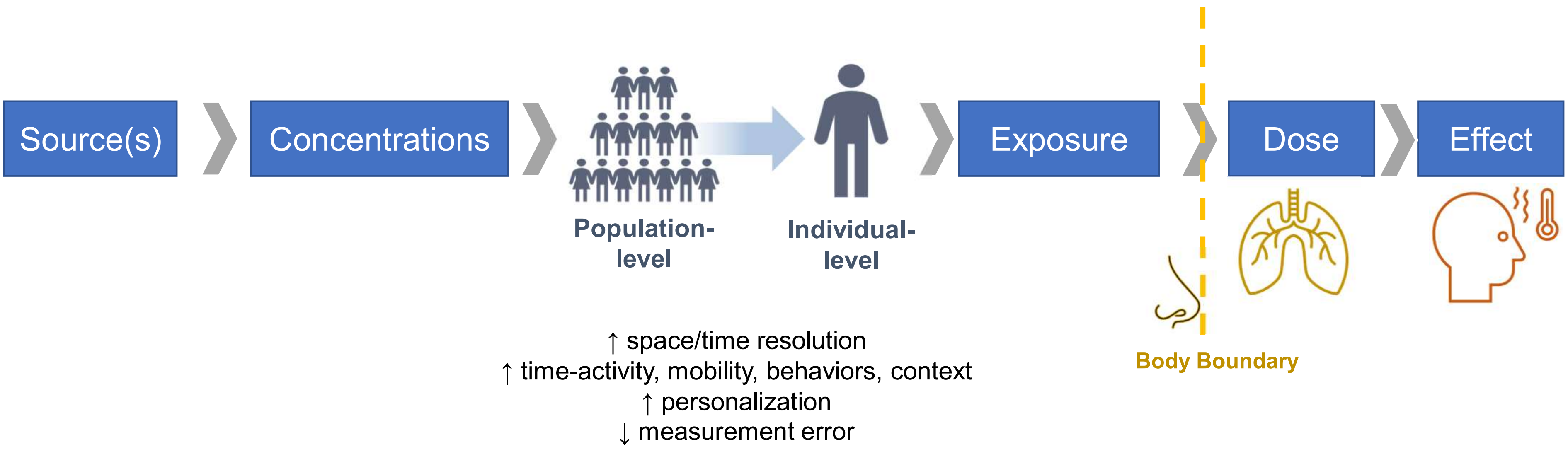
Conceptual Framework



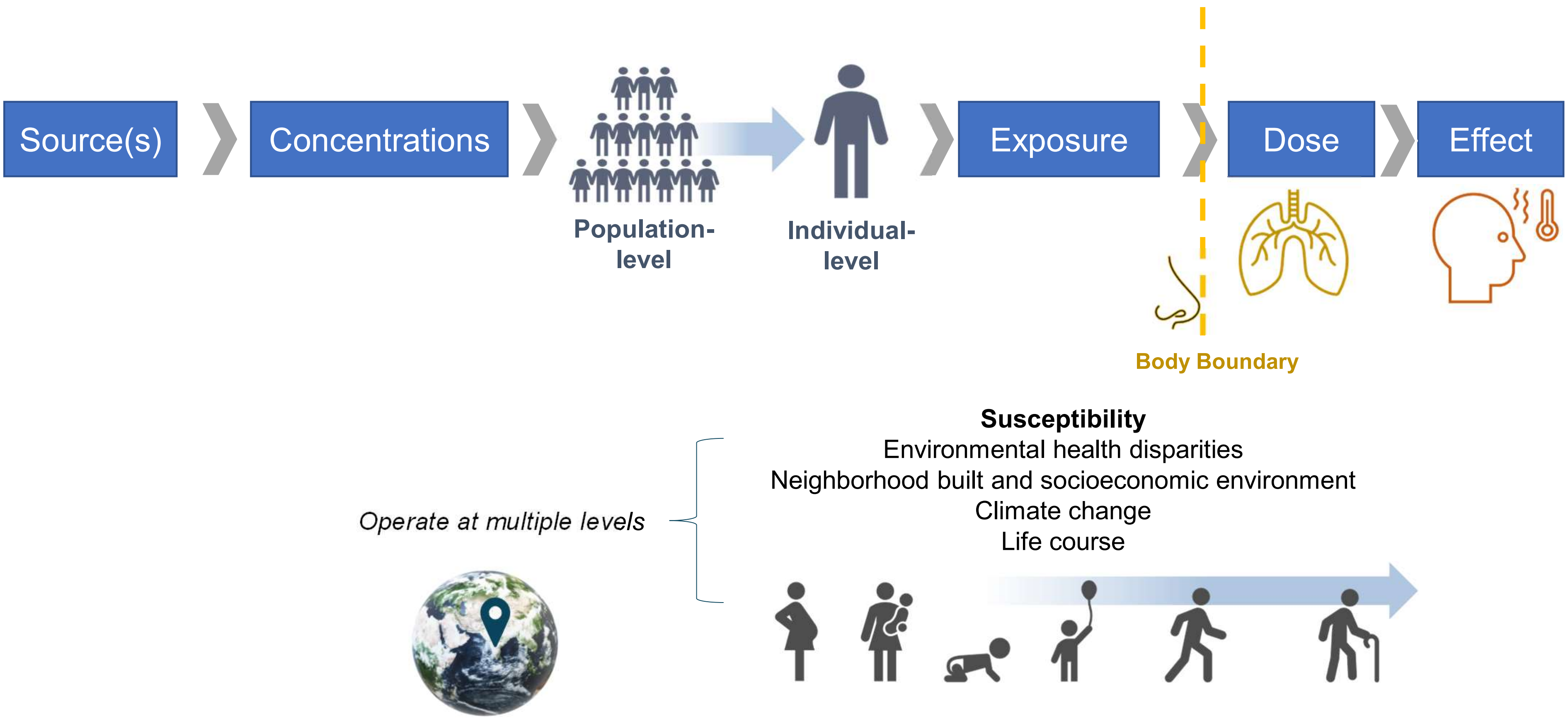
Outdoor, indoor, and personal

Mixtures and co-exposures

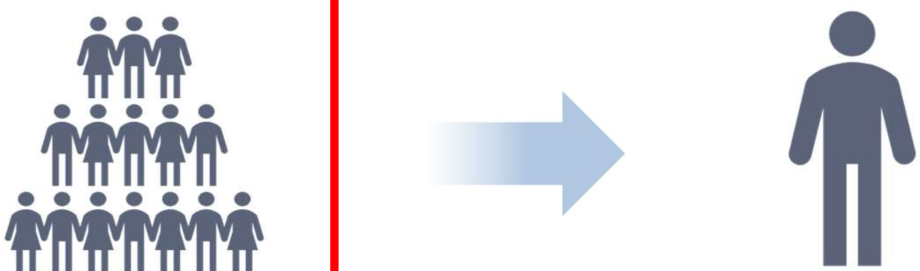
Conceptual Framework



Conceptual Framework



Exposure Assessment Approaches



Population-level

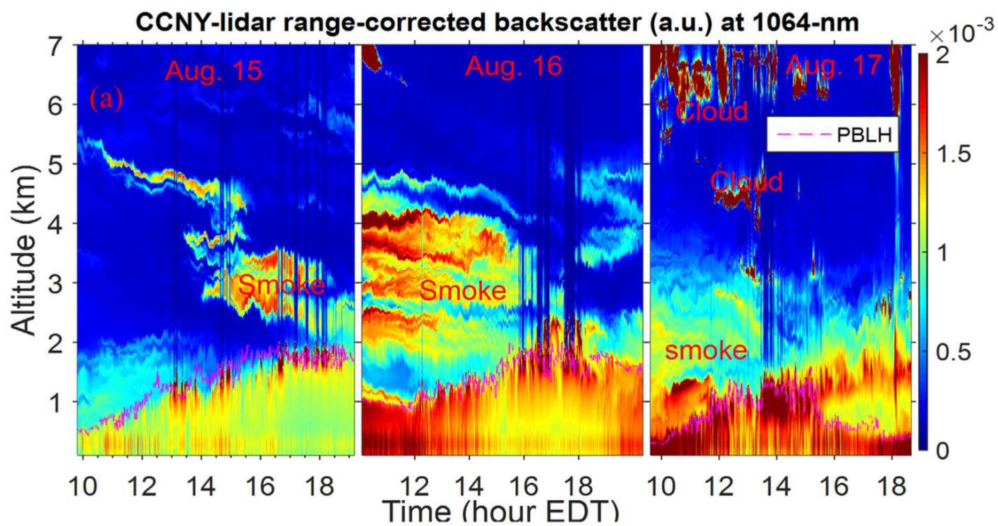
Individual-level

Climate Change & Wildfires

- Wildfires increasing in frequency, duration, and intensity
  - Climate change, land use changes, wildland-urban interface ↑
  - Acute health effects well documented, chronic less researched
- Co-occurring exposures, separate effects from mixture
  - Heat, ozone, toxic ash, etc.
- Susceptibility factors and confounders
  - Co-morbidities, urban heat islands, disparities, SES, etc.
- Personal exposure to wildfire smoke
  - Exposure averting behaviors → ↑ potential for exposure measurement error

Wildfire Smoke

- Complex chemical composition, strongly dependent on what is burning
  - Mobilization of legacy Pb, Cd and Mn from forests (Isley and Taylor, 2020)
- Long range transport, formation of O_3 and SOA
- Size distribution
- Vertical profiles important

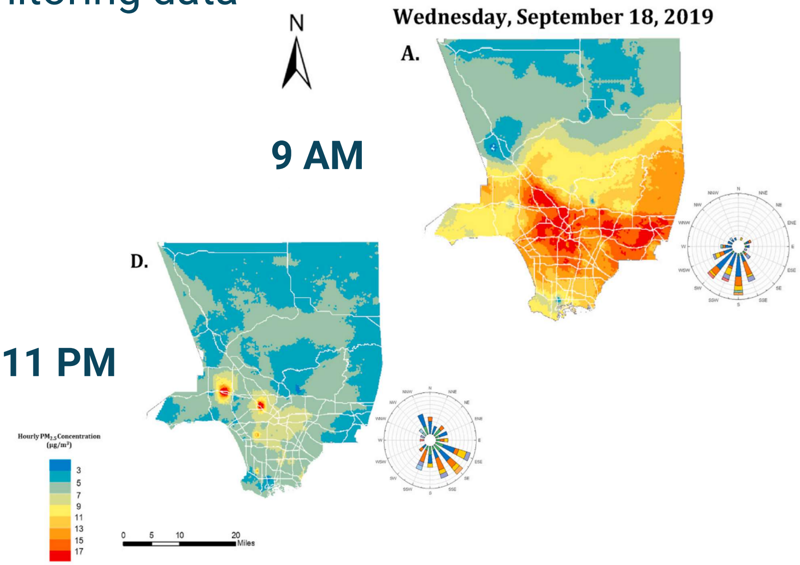


Y. Wu, A.R. Nehrir, X. Ren et al. *Science of the Total Environment 773 (2021) 145030*

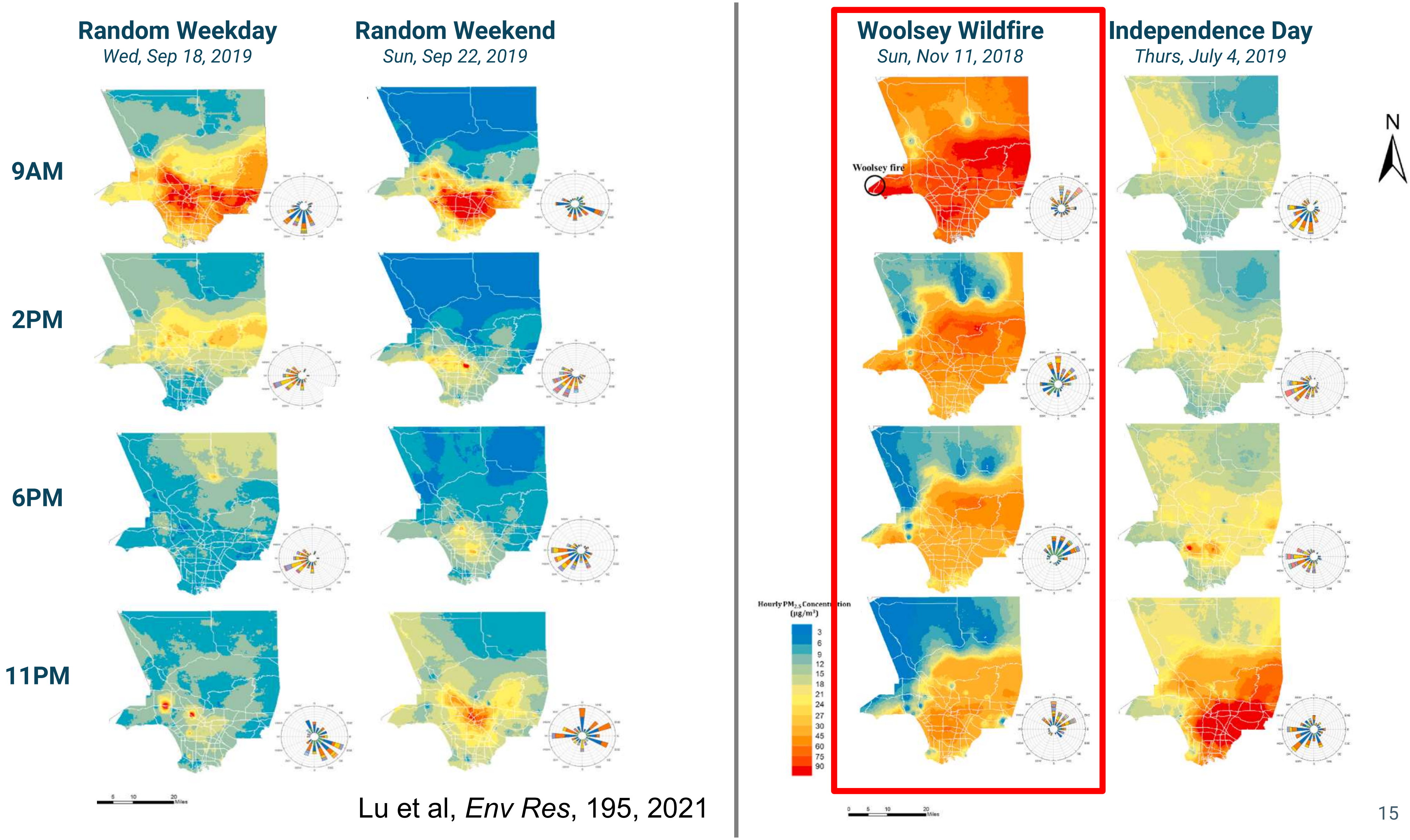
ML-Based Models of Wildfire Smoke and $PM_{2.5}$
Low-Cost Sensor Networks and Remote Sensing

HOURLY, 500M² $PM_{2.5}$ MODEL FOR LA

- Purple Air low-cost crowdsourced monitoring data



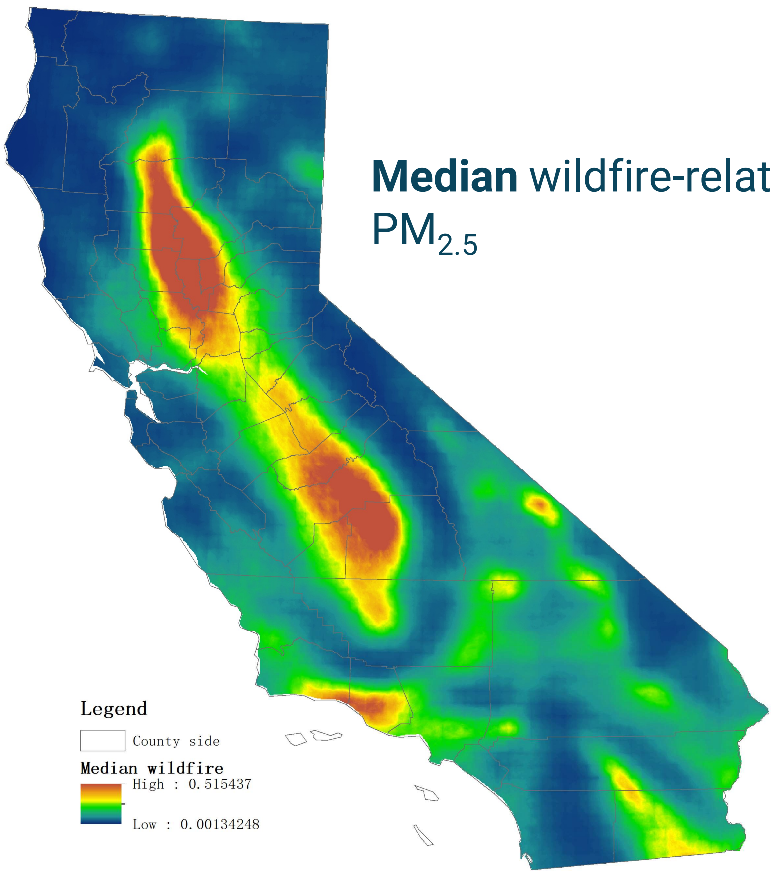
Lu et al, *Env Res*, 195, 2021



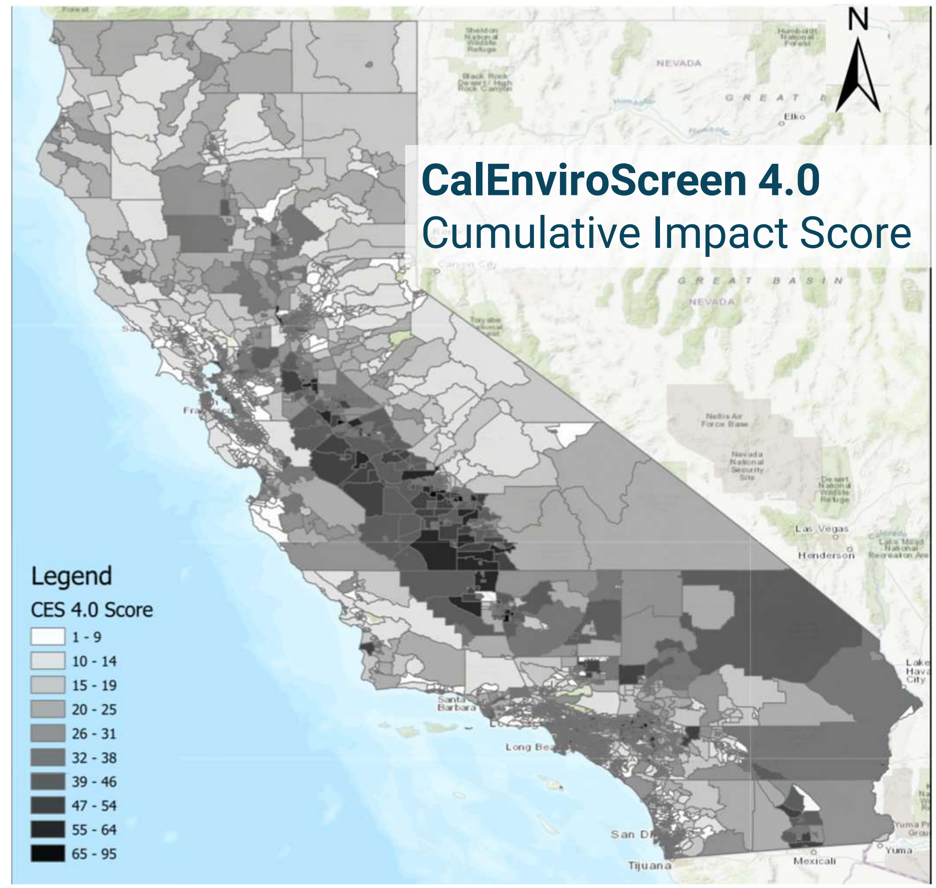
Lu et al, *Env Res*, 195, 2021

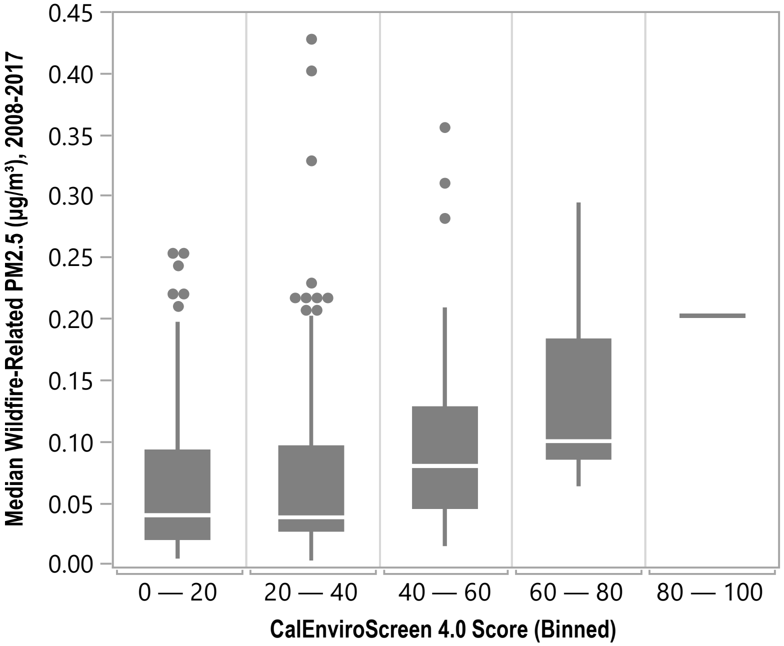
Long Term Exposure Patterns

Over 10 years (2008-2017)

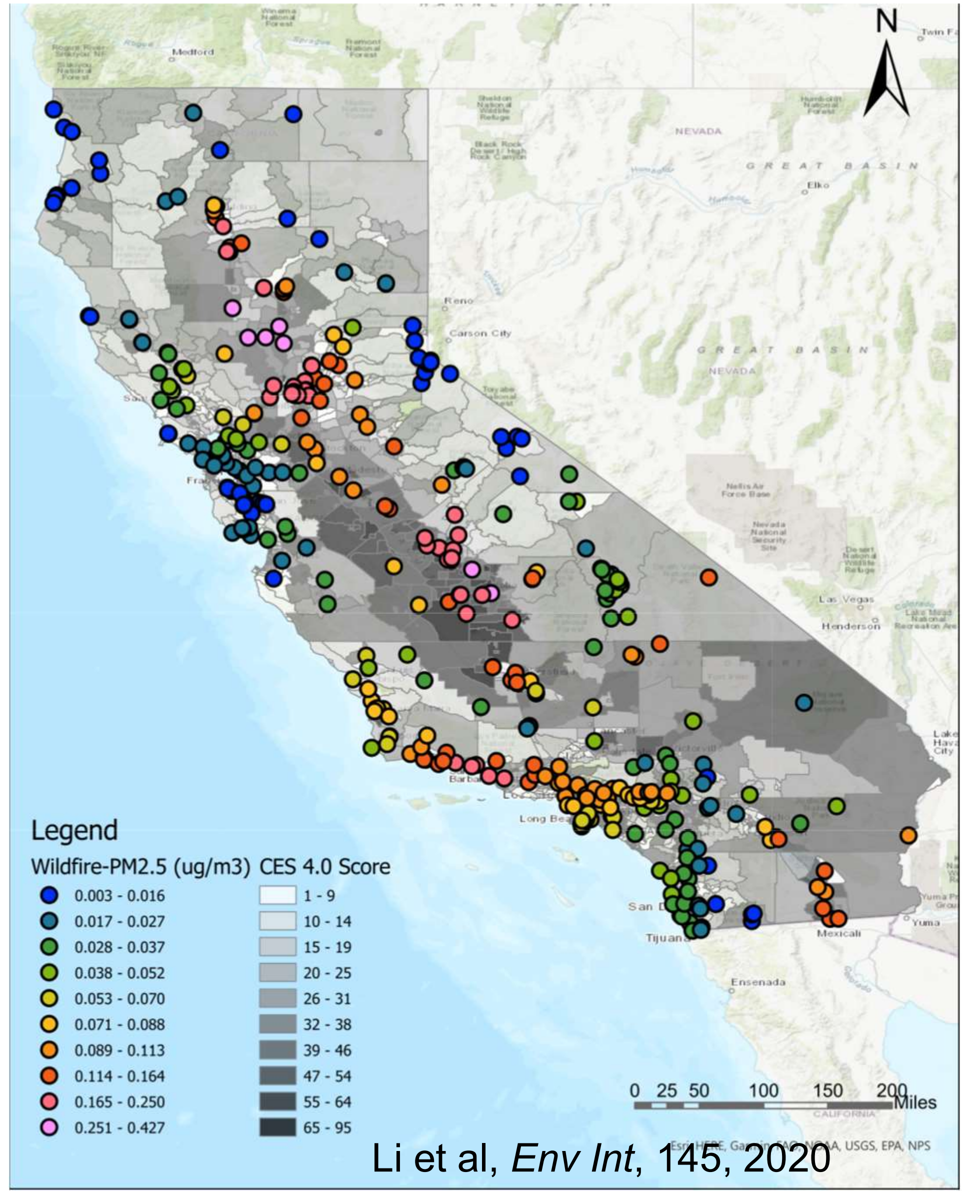


Median wildfire-related $PM_{2.5}$





Highest median weekly wildfire-related $PM_{2.5}$ concentrations across 2008-2017 seen in census tracts with highest CalEnviroScreen 4.0 (California EPA Environmental Justice screening tool) cumulative impact scores



Li et al, *Env Int*, 145, 2020

MADRES Center of Excellence for Environmental Health Disparities Research

Pregnancy Cohort

The MADRES Center is currently recruiting a large, prospective pregnancy cohort of predominantly Hispanic women in the heart of urban Los Angeles, CA, in partnership with local clinics and hospitals.

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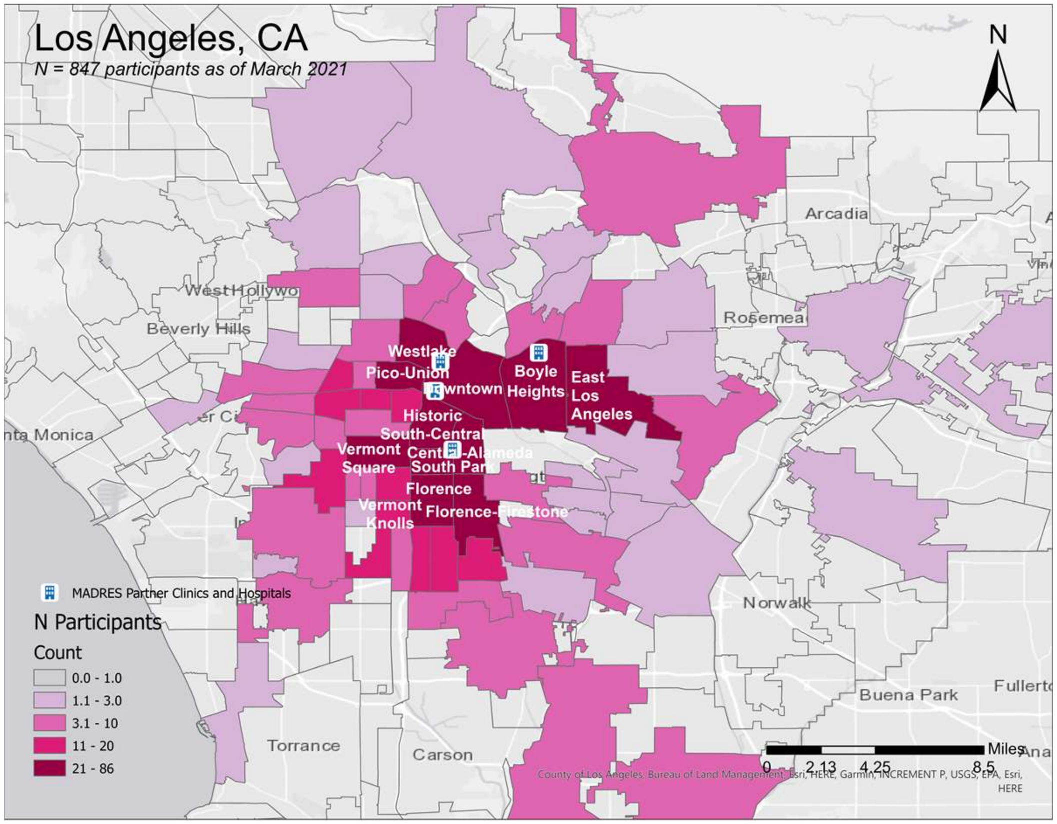
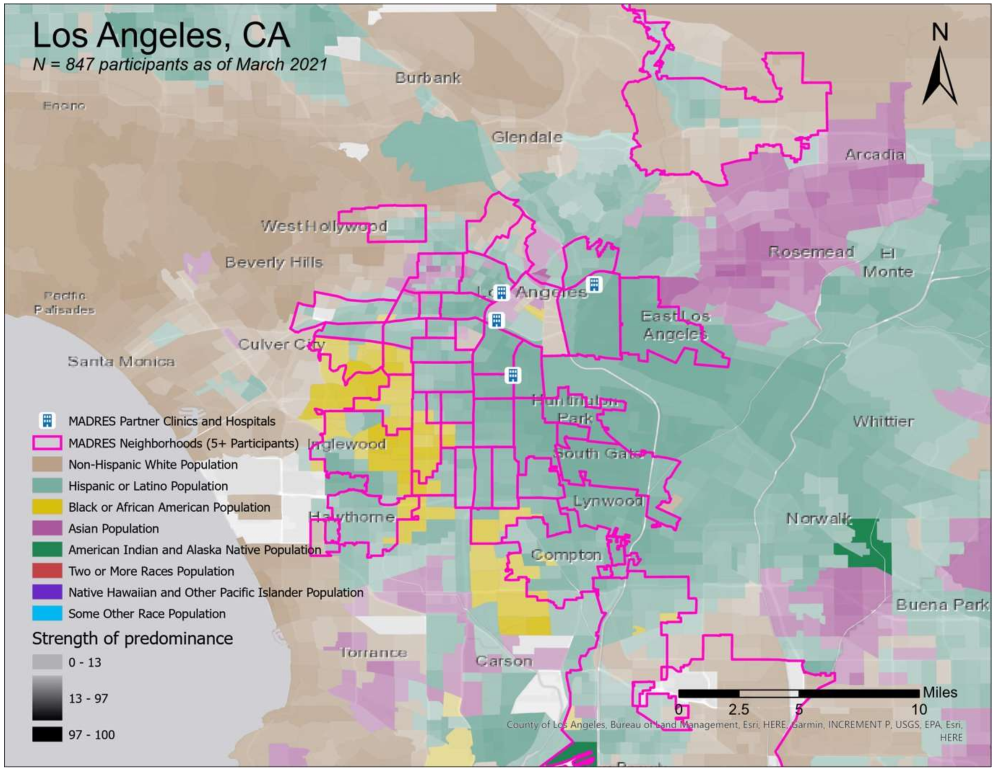
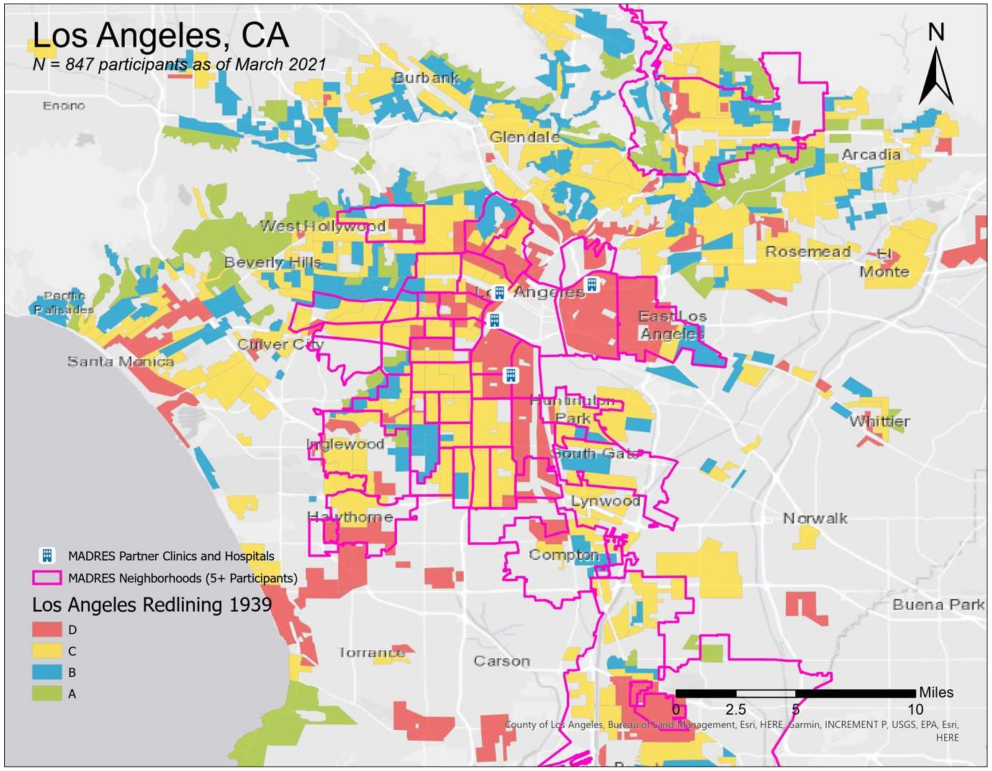
- https://arcg.is/1y8KHn



MADRES Neighborhoods

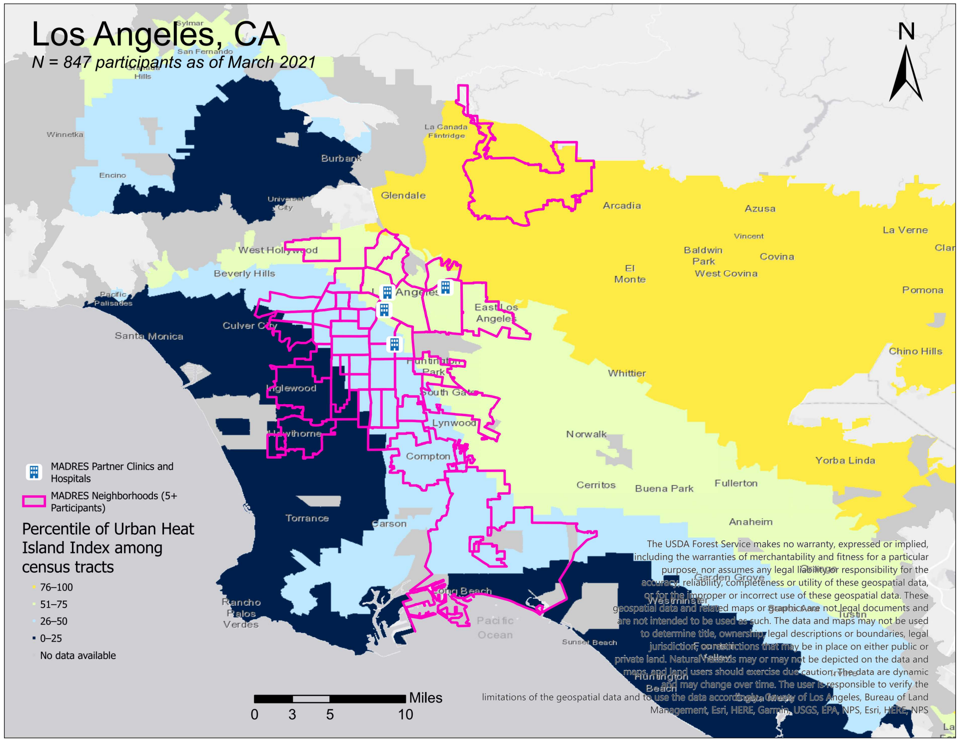
Racial and ethnic disparities





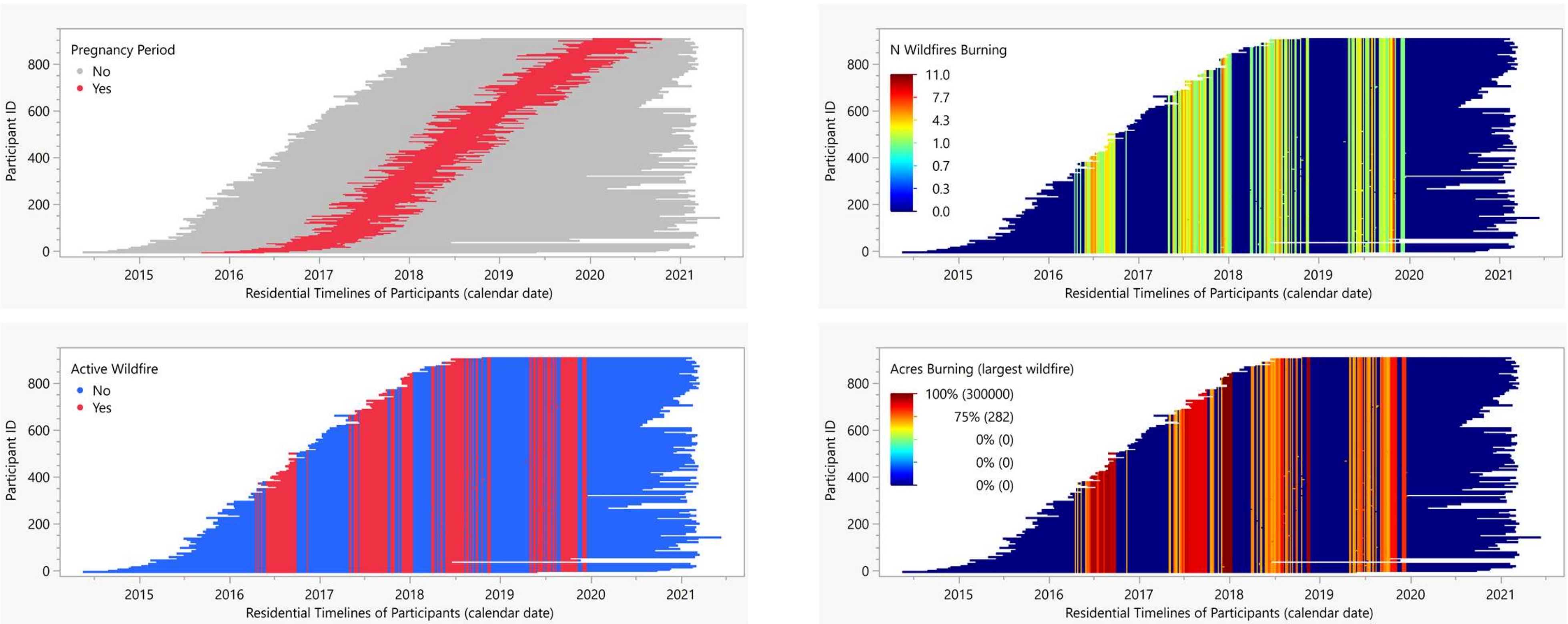
Prenatal Exposure to Wildfire Smoke and Birth Outcomes
Recently funded pilot study, PI Habre

- Last 10 years seen highest N of wildfires *and* temperatures on record in CA
  - Wildfire smoke ~ LBW
  - Extreme temperatures and heat stress ~ LBW
- Investigate joint effects on birth outcomes in MADRES
- Link external wildfire smoke measures to personal $PM_{2.5}$ exposures
  - Measurement error



Urban Heat Island index in MADRES neighborhoods

Prenatal Wildfire Exposure in MADRES

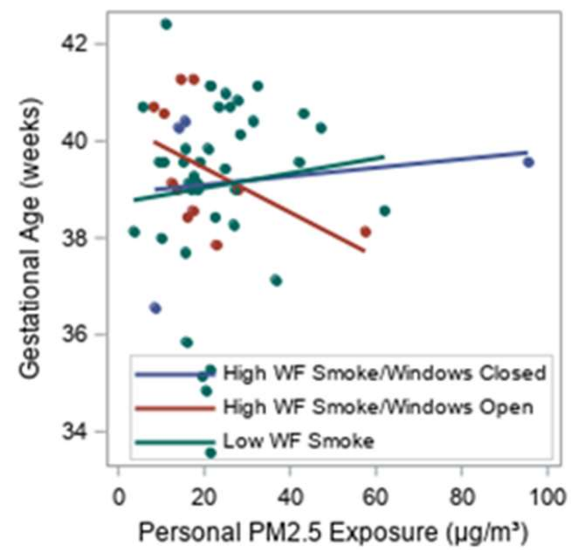


MADRES women experienced 130.5 wildfire days (SD 42.4, min 0, max 211) during pregnancy (n=713), active wildfire data for southern California obtained from CalFIRE.

Preliminary Effects on Fetal Growth

- N wildfire days during pregnancy associated with lower growth-for-gestational age z-scores at birth
  - -0.0755 (95% CI: -0.138, -0.012, p-value=0.0189) per SD (42 days)
  - n=689 babies

Roxana Khalili, PhD

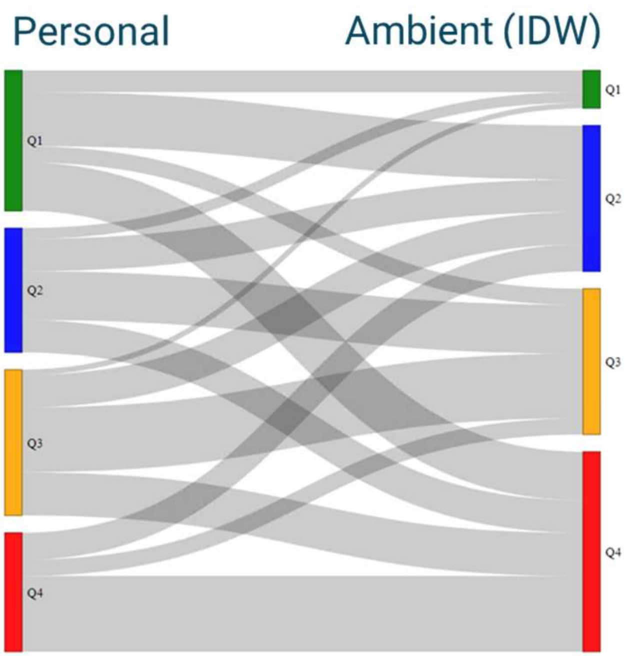


Personal $PM_{2.5}$ exposure ~ smaller gestational age when wildfire smoke high and windows open

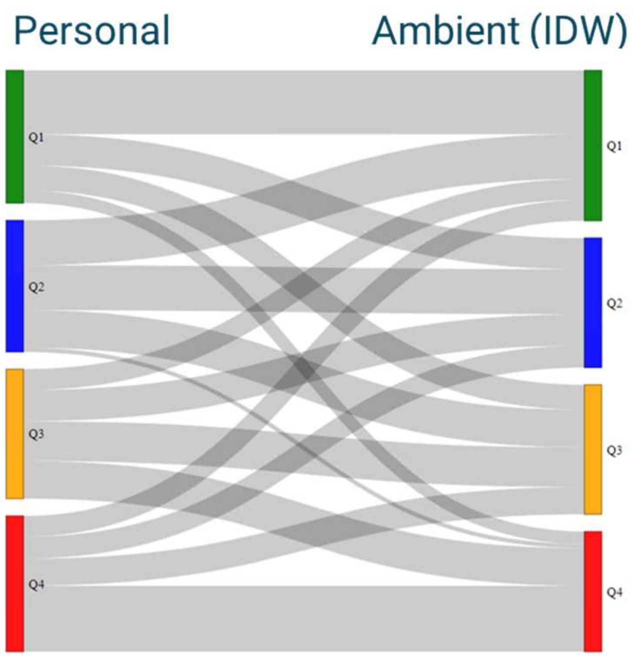
- n=54, preliminary

Karl O'Sharkey, PhD Candidate

PM$_{2.5}$ Exposure Measurement Error Greater During Wildfires



Wildfire_10,000 acres (Yes)

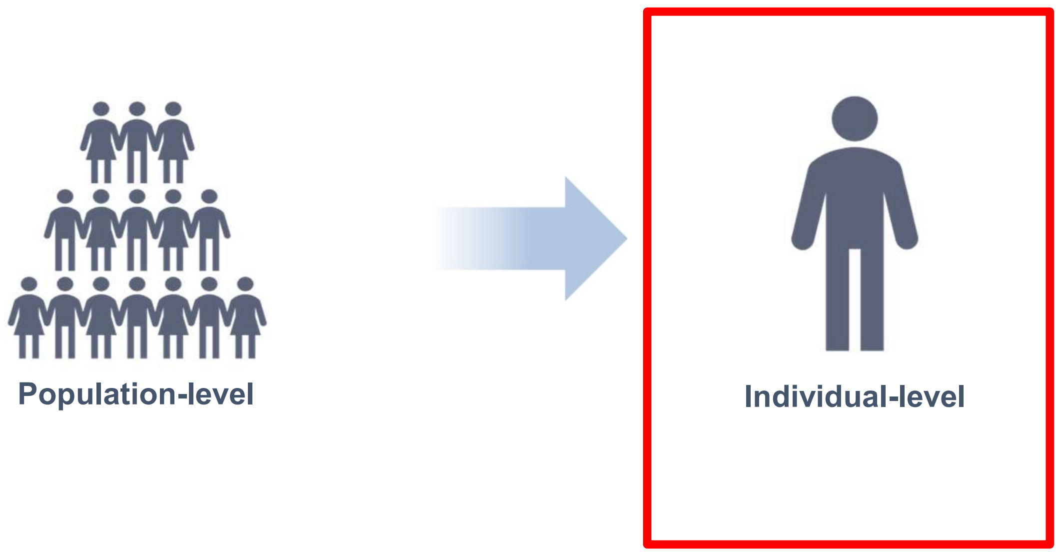


Wildfire_10,000 acres (No)

Yisi Liu, PhD

*Results were similar for smaller wildfires as well (<5,000 acres and <1,000 acres)

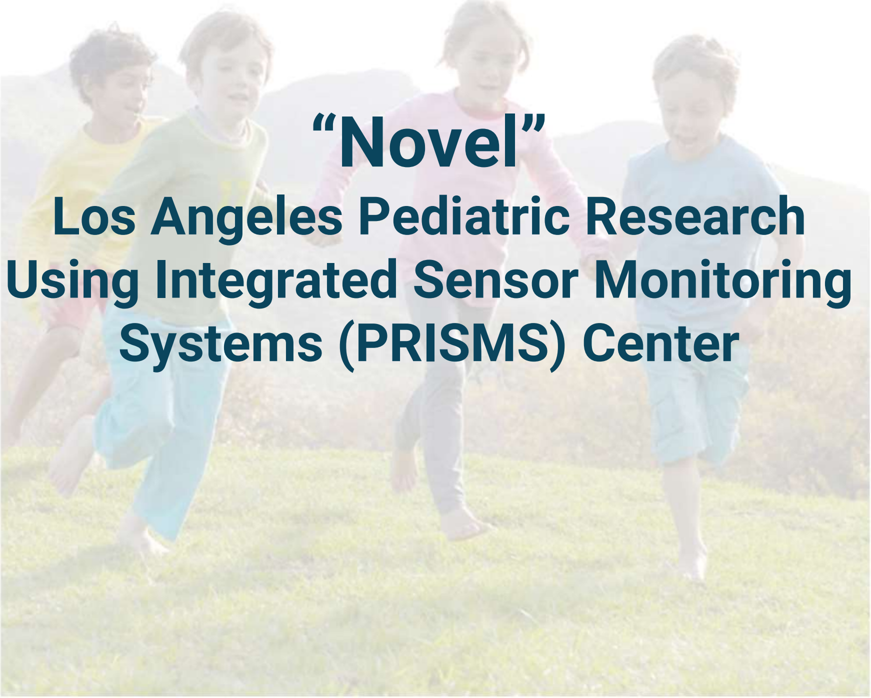
Exposure Assessment Approaches



Two Approaches to Personal Monitoring

“Classic”

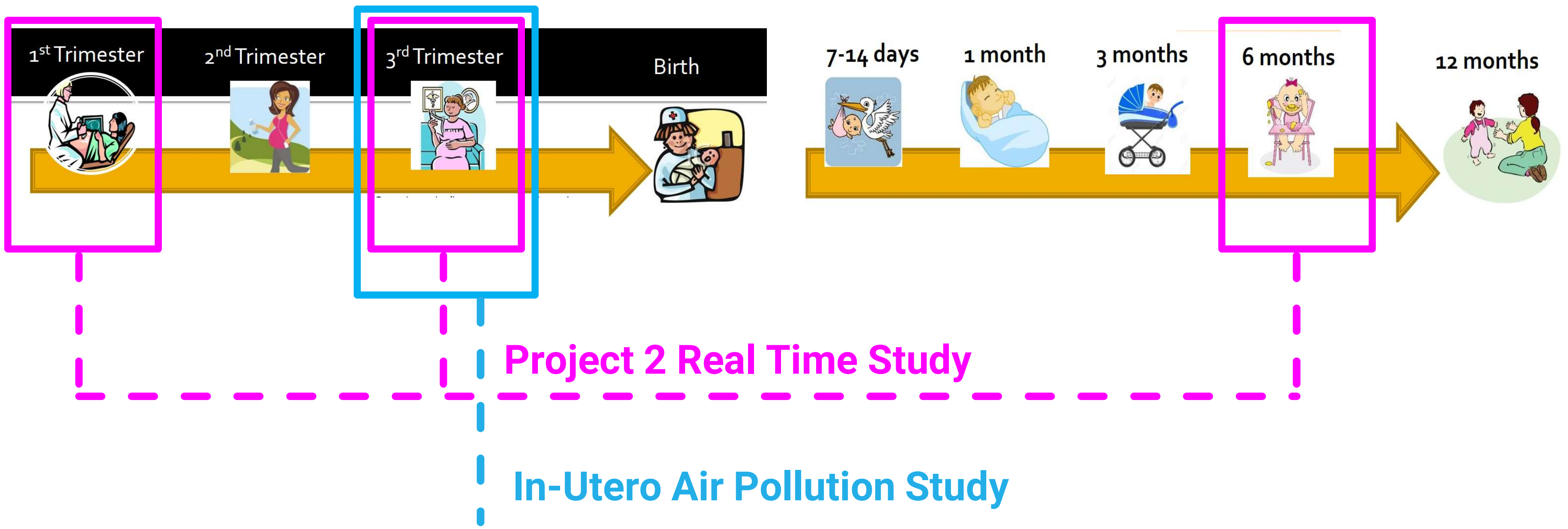
MADRES Environmental Health Disparities Center



“Novel”

Los Angeles Pediatric Research Using Integrated Sensor Monitoring Systems (PRISMS) Center

Personal Monitoring in MADRES

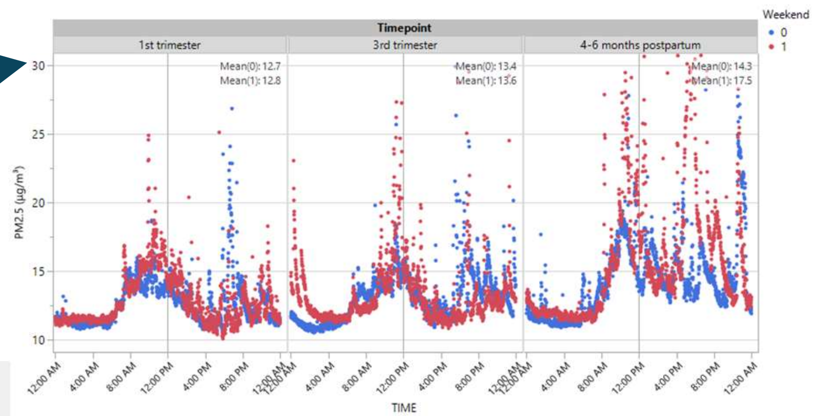


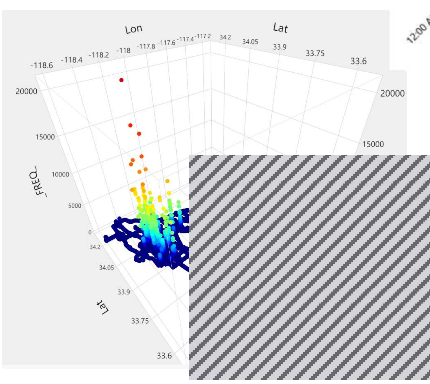
Bastain T *et al., BMC Pregnancy Childbirth*. 2019; 19(1):189

Personal GPS + Air Pollution Monitoring

- Continuous and integrated methods, paired with GPS and EMA mobile surveys during pregnancy and early postpartum

RTI microPEM



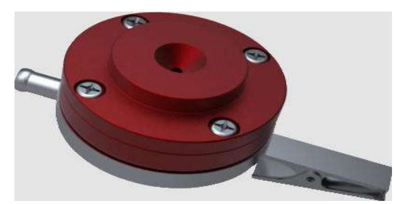


GPS and EMA apps

Sensidyne GilAir Plus pumps

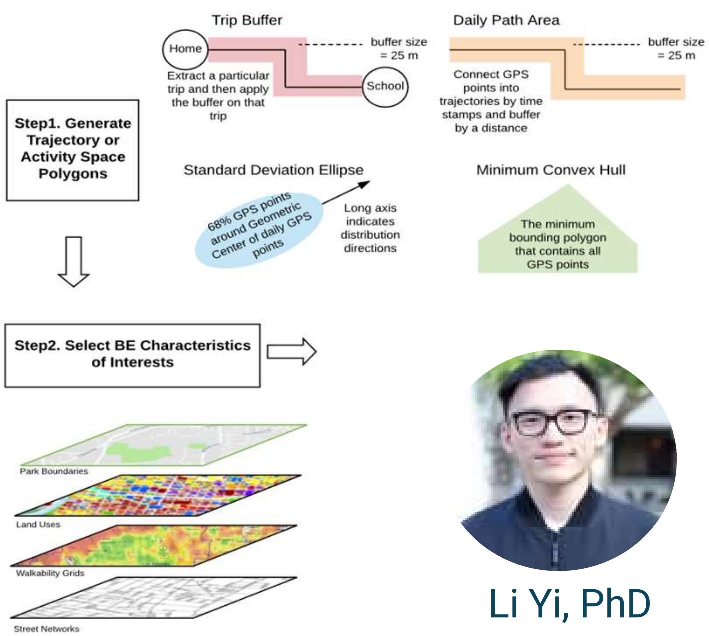
Teflon filters

Harvard PEMs

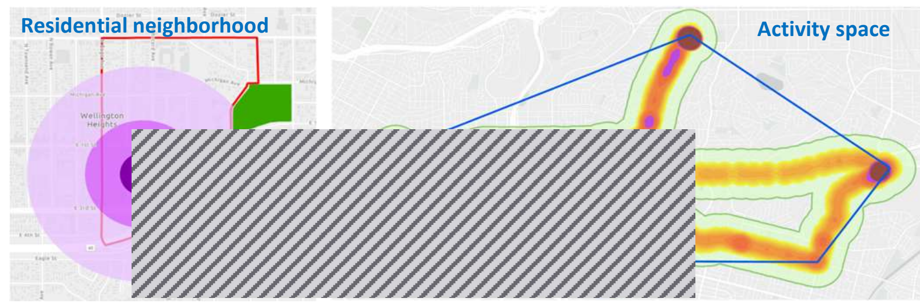


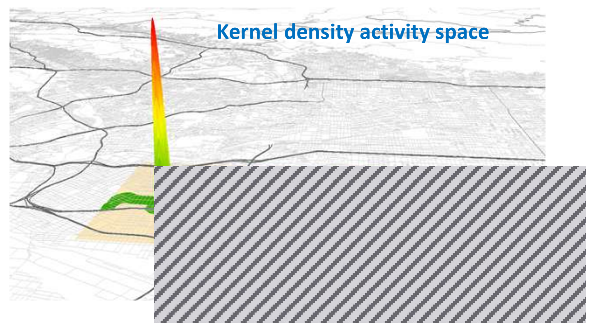
Incorporating Mobility into Exposure

- High-res GPS to assess exposures within activity spaces



Li Yi, PhD

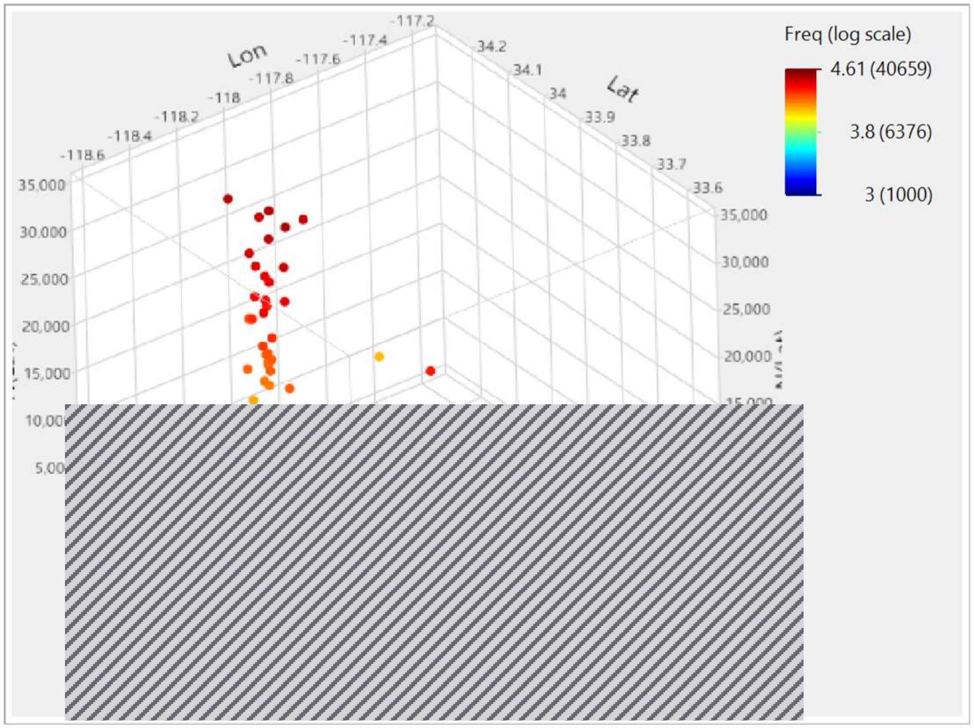




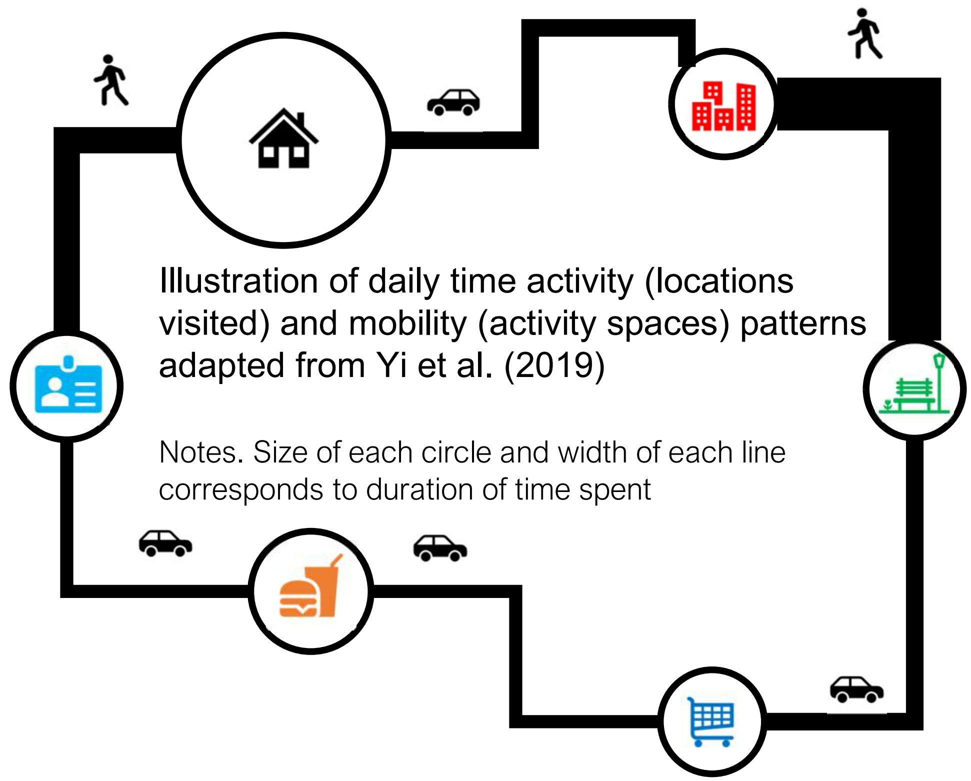
Yan Xu, PhD

Li et al, *Health and Place*, 60, 2020

Trip Stay Detection and Time-Activity Patterns



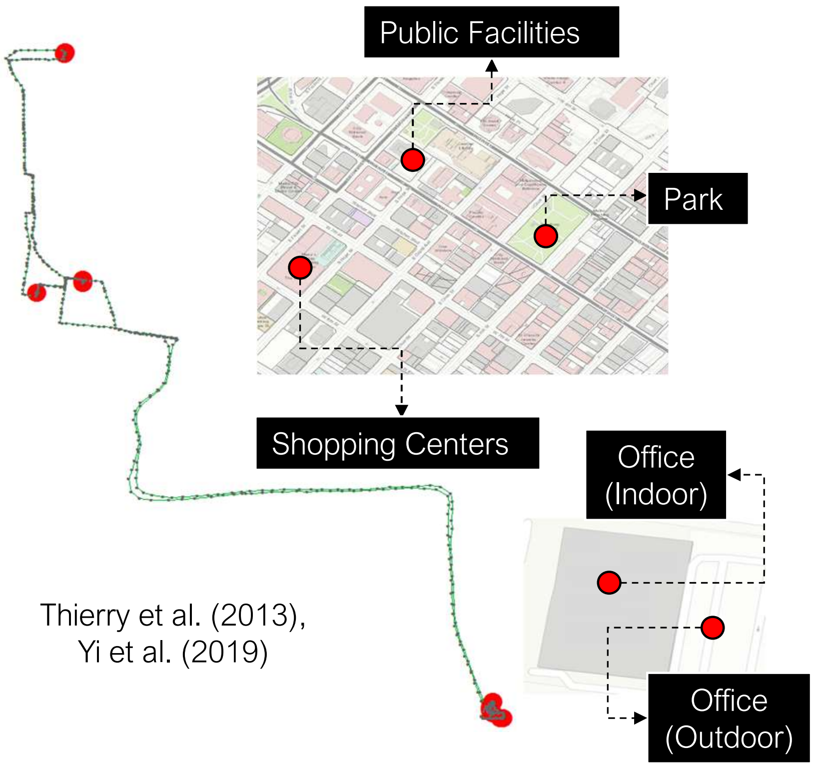
MADRES 10-sec resolved GPS data (n=62 women, 12 days each distributed across pregnancy)



Li et al., *Spatial and Spatiotemporal Epidemiology*, 2022

Context and μEnv Classification

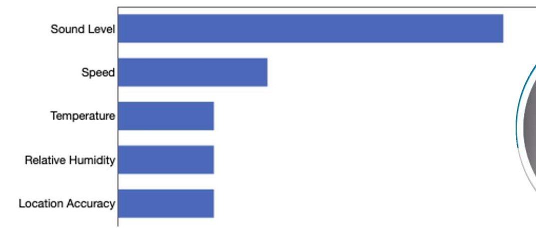
Using GPS/GIS (left) or smartphone sensors (right)



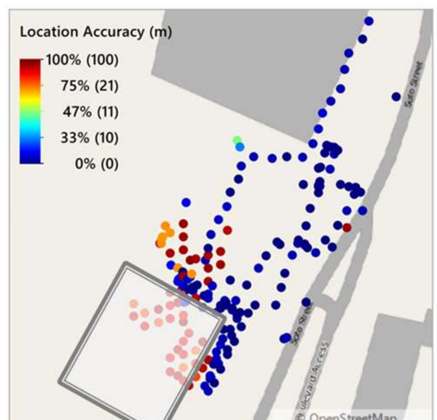
Thierry et al. (2013),
Yi et al. (2019)

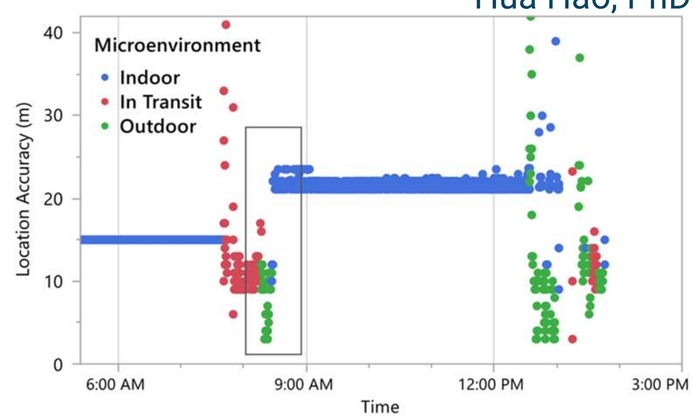
Li Yi, PhD

Figure S3. Top 10 important features for overall microenvironment prediction ranked by drop-column method from the optimal, final model in S1 (random forests algorithm with 31 features).



Hua Hao, PhD

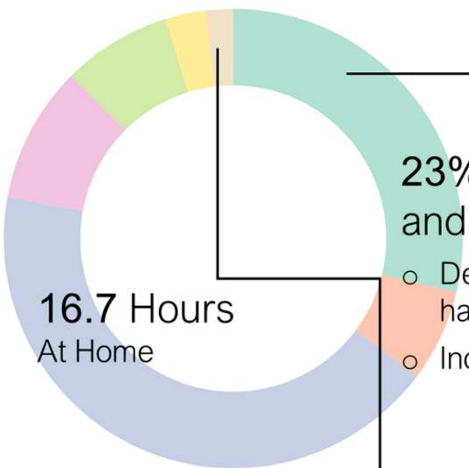




Hao H, Girguis M, Eckel S, Hosseini A, Lewinger J P, Deng H, Li K, Bui A, Habre. Microenvironmental Time-Activity Classification Using Smartphone Sensor Data for Personal Air Pollution Exposure Assessment. *Under review.*

GPS-Based Time-Activity and Mobility Patterns

Li Yi, PhD

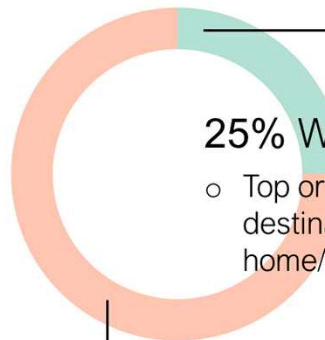


23% Visits to Commercial and Service Locations

- Decreased at postpartum or had at least one child
- Increased if employed

2% Visits to Parks and Open Space

- Increased during weekends



25% Walking Trips

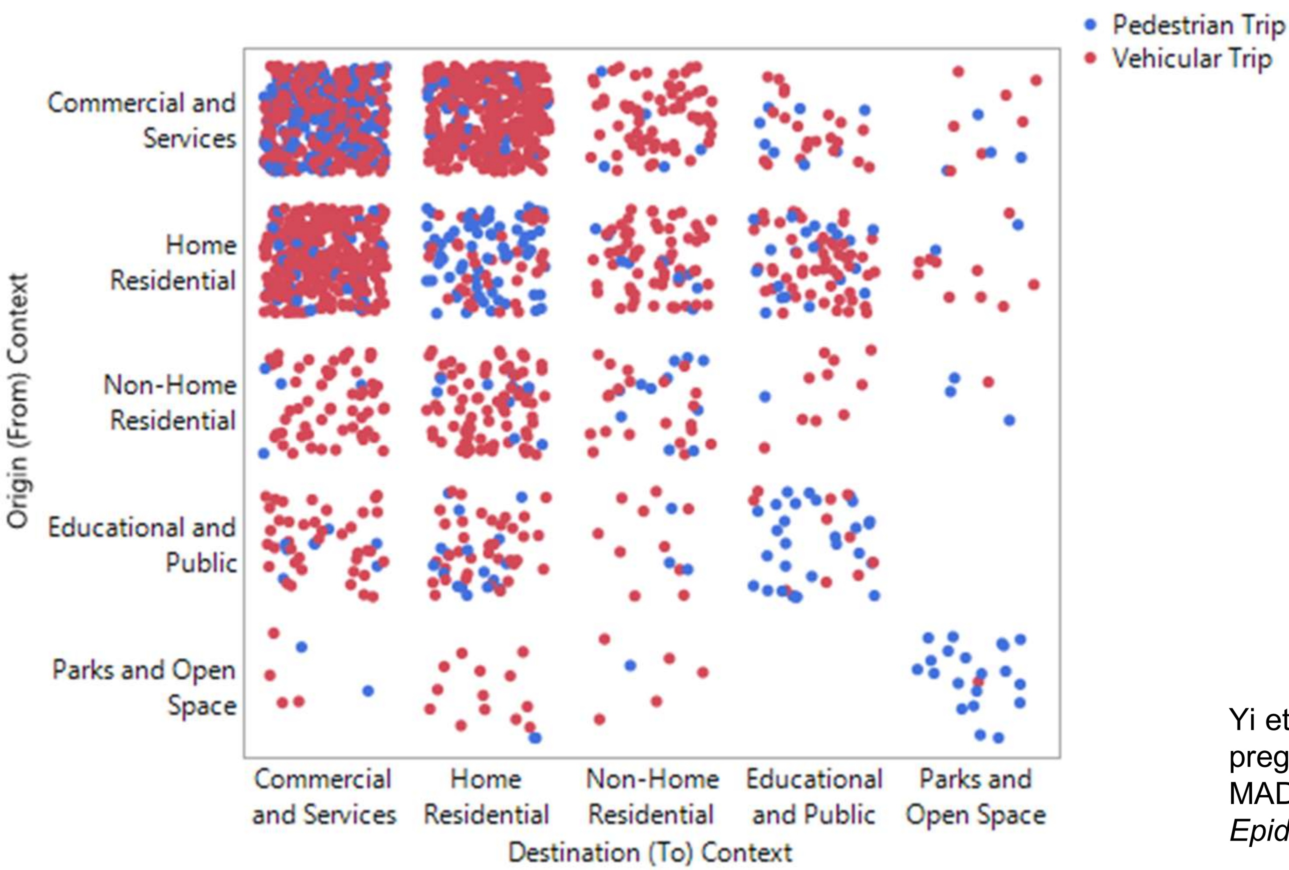
- Top origins and destinations include home/commercial

75% Vehicular Trips

- Decreased at postpartum & weekend days
- Increased if higher education attainments

Yi et al., Time-activity and daily mobility patterns during pregnancy and early postpartum – evidence from the MADRES cohort. *Spatial and Spatio-temporal Epidemiology*, 2022

Trip Origins and Destinations

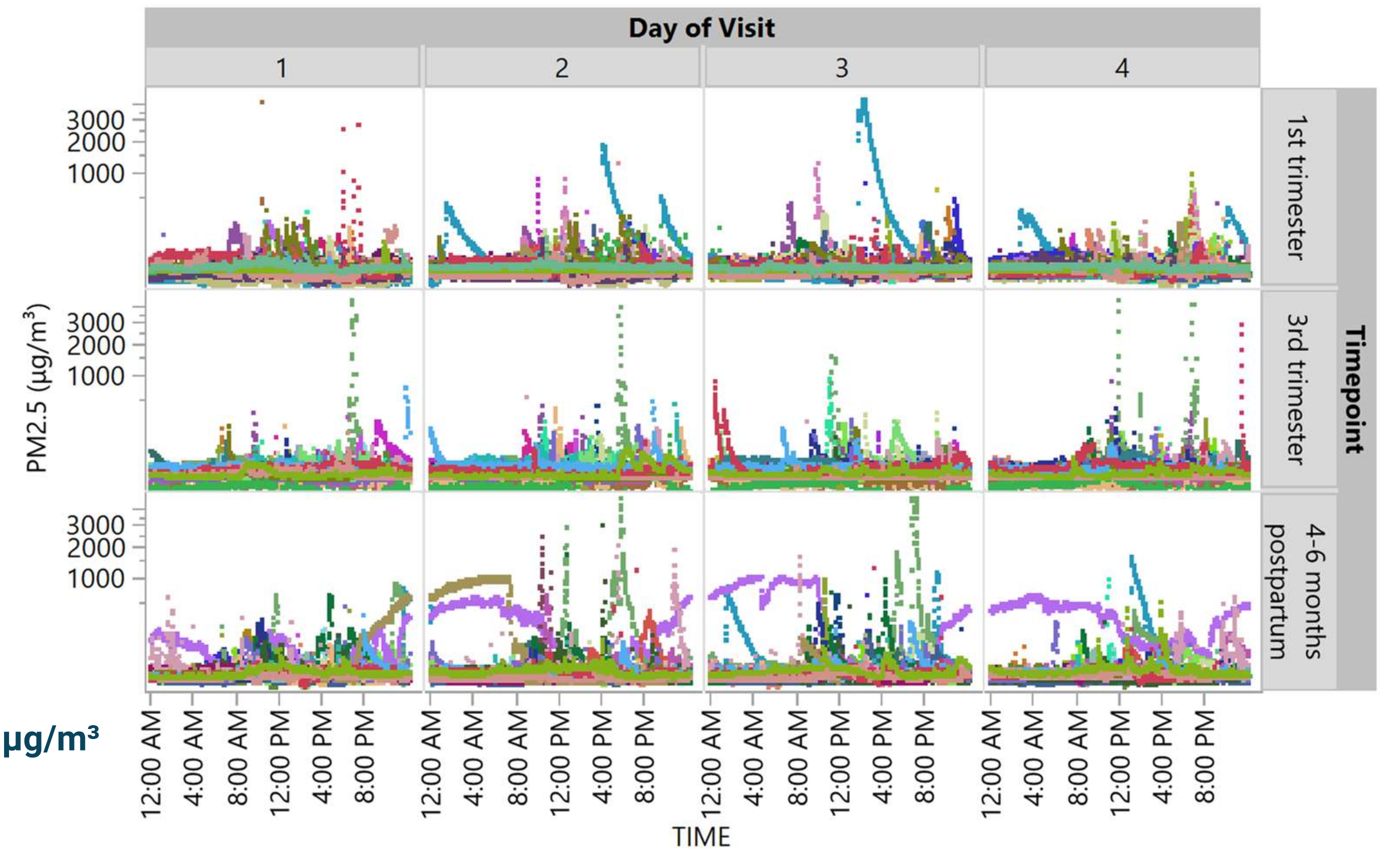


- Vehicular trips 3x ↑ than pedestrian
- Most pedestrian trips between or within commercial/services locations
- Most vehicular trips between home and commercial/services locations

Yi et al., Time-activity and daily mobility patterns during pregnancy and early postpartum – evidence from the MADRES cohort. *Spatial and Spatio-temporal Epidemiology*, 2022

Personal $PM_{2.5}$ Exposures

n=162 four-day samples, from 59 pregnant women

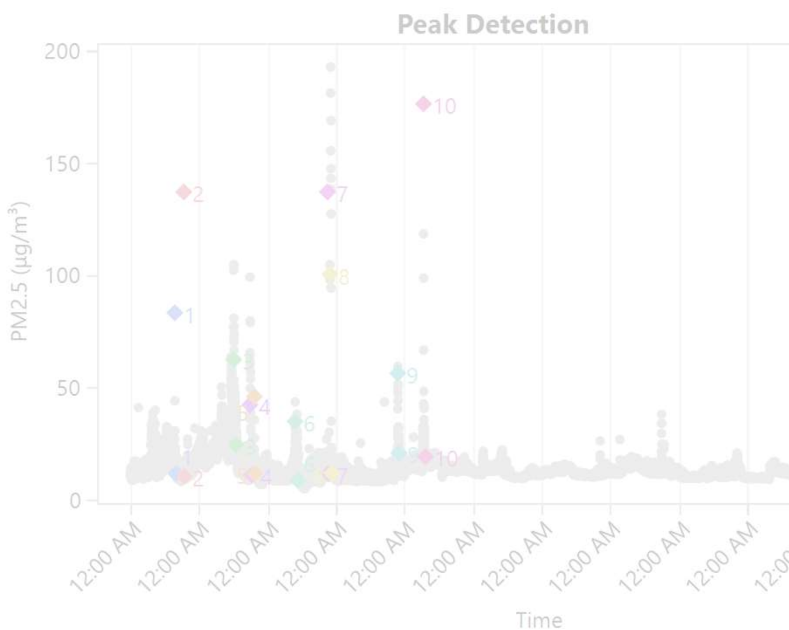


Mean (SD) **16.9 (68.0) µg/m³**
N **870,547**

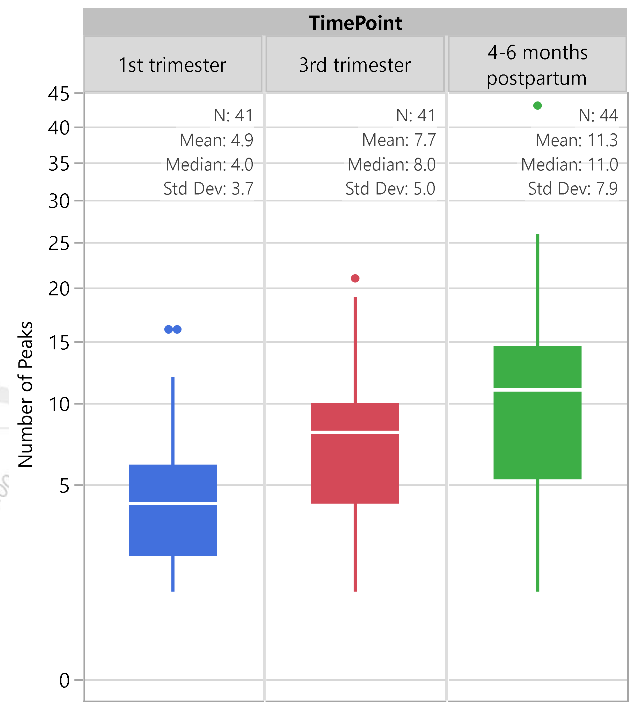
1-min calibrated data

Peaks Detection Algorithm

Example



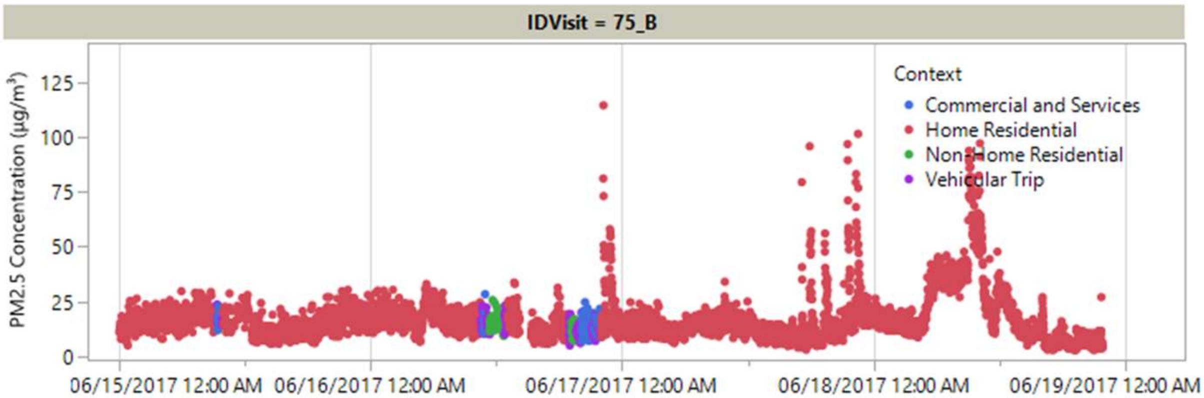
Visit-level
Significant differences

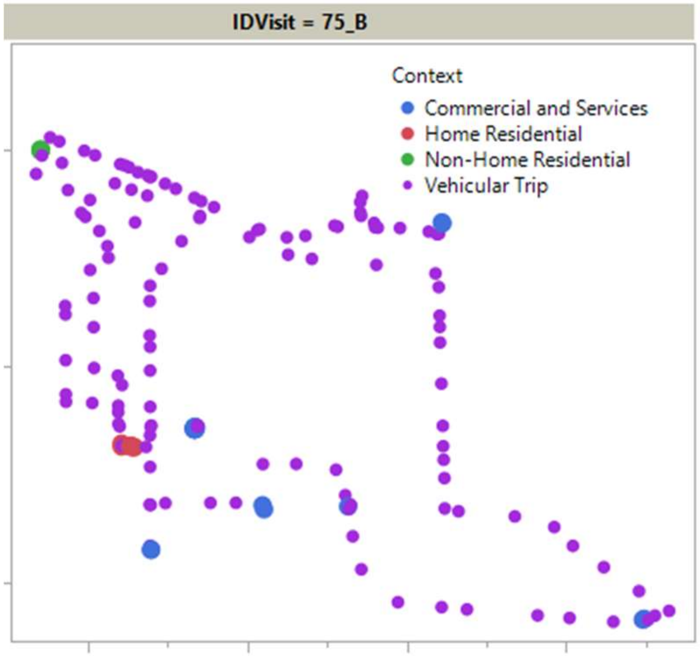


Based on Wallace, Williams, Rea and Croghan, *Atmospheric Environment* 40: 2006.

Personal $PM_{2.5}$ Exposure by Context

Personal $PM_{2.5}$ exposure time-series with classified trips, stays and context





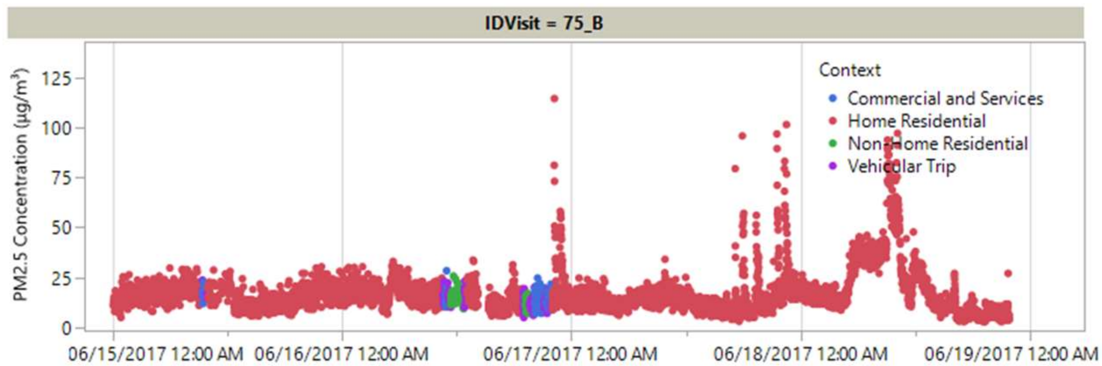
Corresponding GPS trajectory

$PM_{2.5}$ Peaks by Context and µEnv

n=593 peaks

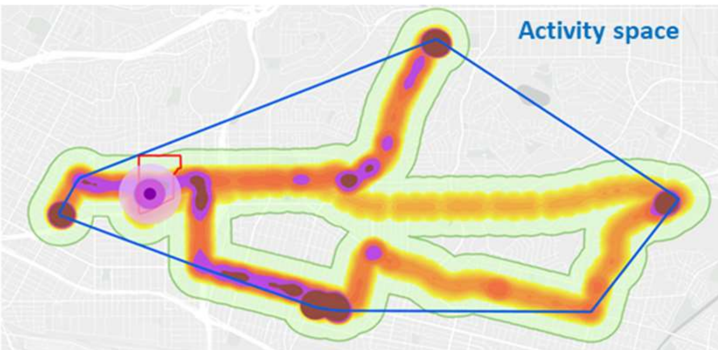
Context	Overall N	% of Total
Home Residential	**302**	**77%**
Commercial and Services	45	11%
Non-Home Residential	22	6%
Educational and Public Fac.	10	3%
Parks and Open Space	9	2%
Other	4	1%

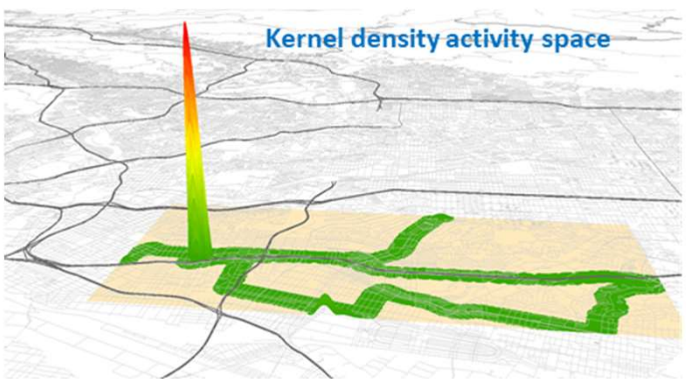
Personal $PM_{2.5}$ exposure time-series with classified trips, stays and context



Context	Indoor N	Row %	Outdoor N	Row %
Home Residential	**280**	**93%**	22	7%
Commercial and Services	25	56%	20	44%
Non-Home Residential	13	68%	6	32%
Educational and Public Fac.	5	50%	5	50%
Parks and Open Space	0	0%	8	100%
Other	1	50%	1	50%

Activity Spaces and Personal $PM_{2.5}$ Exposure





Activity Space exposures

- NDVI within KDE area
- Park area within DPA
- Primary roads within KDE area
- Secondary roads within DPA

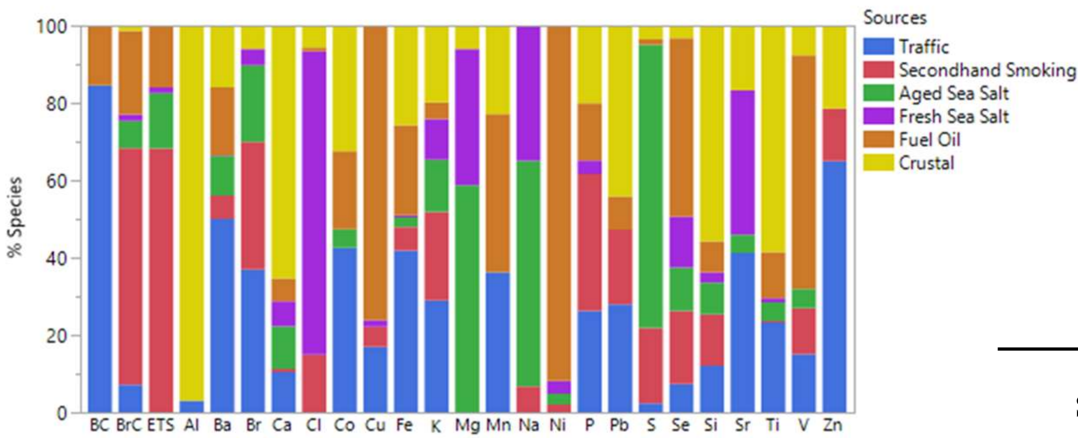
Yan Xu, PhD

Association with Personal $PM_{2.5}$ Exposure

- Green: Negative association
- Red: Positive association

Xu Y et al., The Impact of GPS-derived Activity Spaces on Personal $PM_{2.5}$ Exposures in the MADRES Cohort. *Environment Research.* Under Review.

Sources of Personal $PM_{2.5}$ Exposure



Yan Xu, PhD

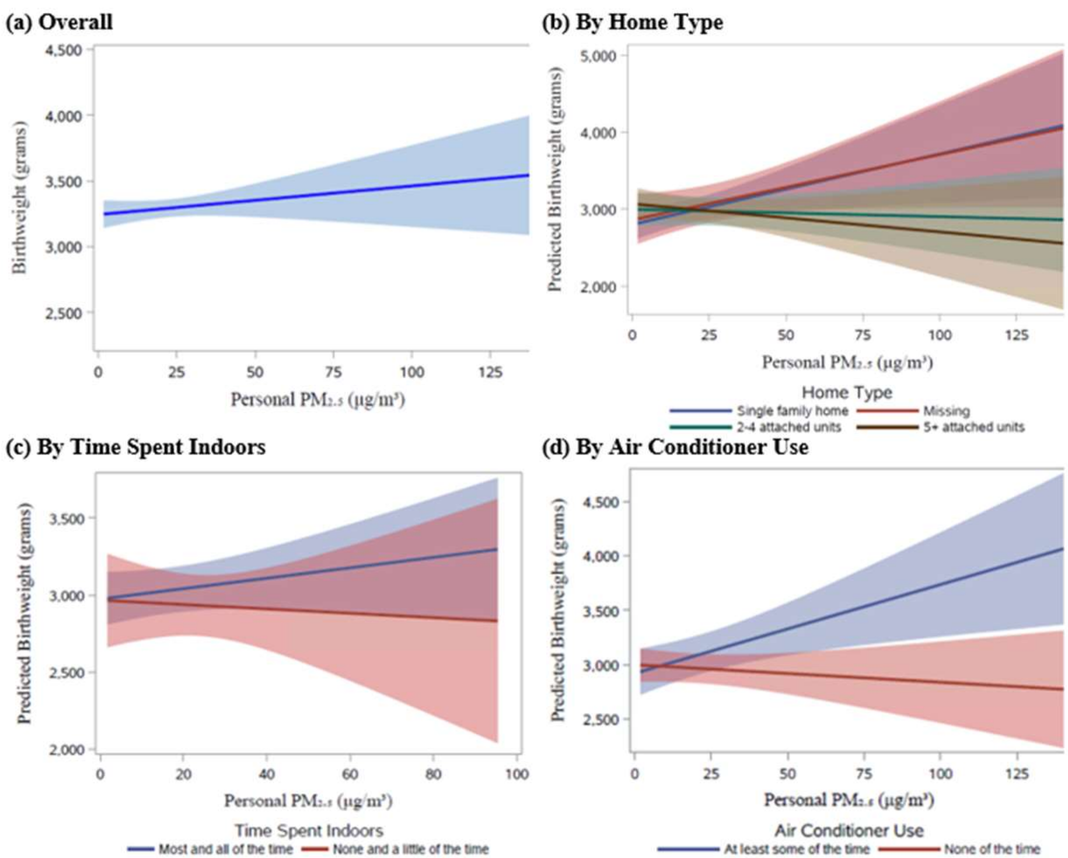
Sources identified and characteristic species

- Secondhand smoking (BrC, ETS, Br)
- Crustal (Al, Ca, Si, Ti)
- Fuel Oil (Ni, V)
- Aged Sea Salt (Na, Mg, S)
- Fresh Sea Salt (Cl, Na, Mg)
- Traffic (BC, Ba, Zn)

Sources	Average mass contribution ($\mu g/m^3$)	Percent Contributions (%)
Secondhand Smoking	11.7	64.2
Crustal	2.3	12.6
Fuel Oil	2.1	11.4
Aged Sea Salt	0.9	4.8
Fresh Sea Salt	0.8	4.5
Traffic	0.4	2.4

Xu Y et al., Sources of Personal $PM_{2.5}$ Exposure in the MADRES Pregnancy Cohort. *JESEE.* In Submission.

Personal $PM_{2.5}$ Exposure by Origin and Birthweight



Karl O'Sharkey, PhD Candidate

O'Sharkey et al., In-Utero Personal Exposure to $PM_{2.5}$ Impacted by Indoor and Outdoor Sources in the MADRES Cohort. *Environmental Advances.* 2022.

National Academies of Sciences, Engineering and Medicine
Emerging Science on Indoor Chemistry Consensus Study

Emerging Science on Indoor Chemistry

Study Director
Dr. Megan Harries, *Board on Chemical Sciences and Technology, NASEM*

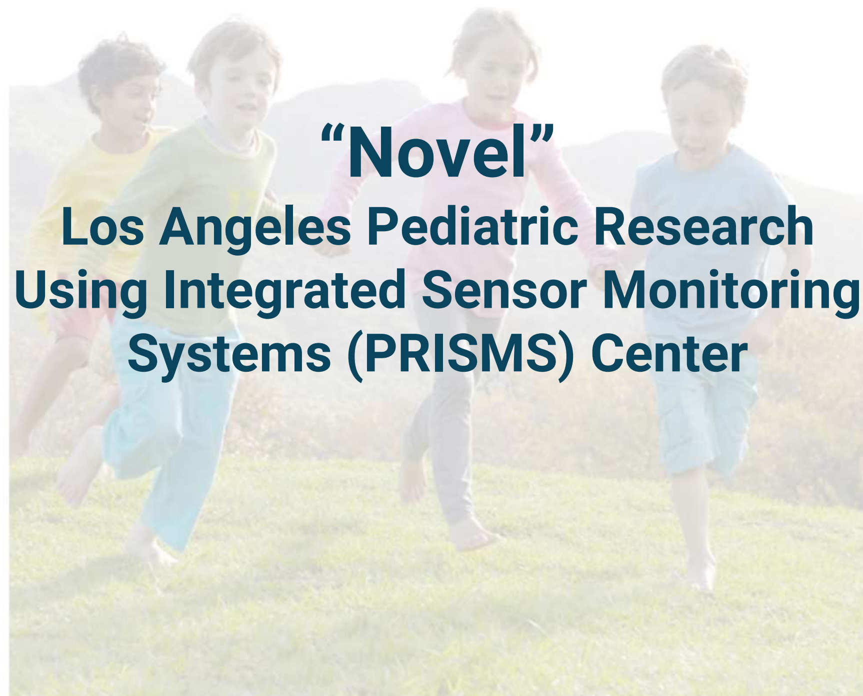
Committee Chair
Dr. David Dorman, *North Carolina State University*

This study will examine the state of science regarding chemicals in indoor air. Our team of scientific experts will focus on under-reported chemical science discoveries and how these findings shine light on the link between chemical exposure, air quality, and human health. The final report will explore potential opportunities for new scientific research. It will also identify what research will be most critical to understanding the chemical composition of indoor air and adverse exposures. The environments in this study will be limited to non-industrial exposure within buildings.

https://www.nationalacademies.org/our-work/emerging-science-on-indoor-chemistry

Two Approaches to Personal Monitoring

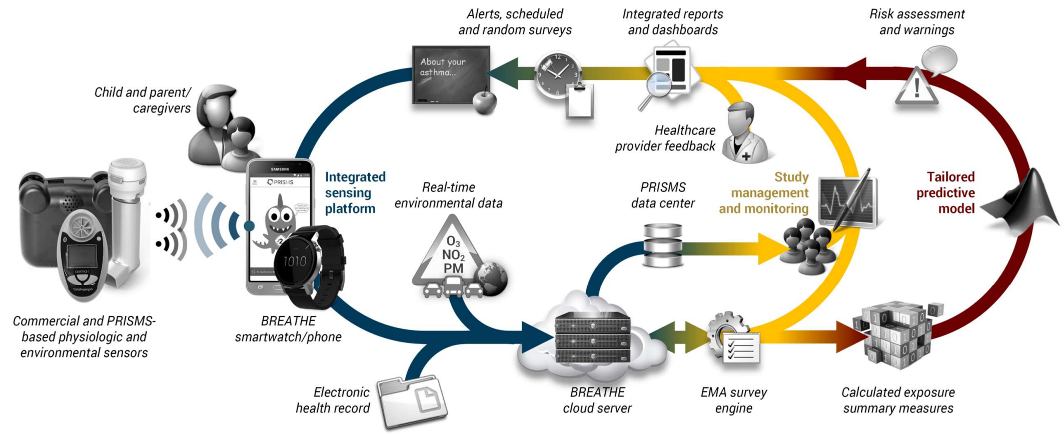
“Classic”
MADRES Environmental Health Disparities Center



“Novel”
Los Angeles Pediatric Research Using Integrated Sensor Monitoring Systems (PRISMS) Center

Informatics Platform for Sensor-Based Studies

Real-time, Wireless, High Resolution



Biomedical REAl-Time Health Evaluation (BREATHE) informatics platform developed by the Los Angeles PRISMS Center (NIBIB U54EB022002)

Bui et al, *JAMIA Open*, 3(2), 2020

https://youtu.be/6y0tzsfApw4

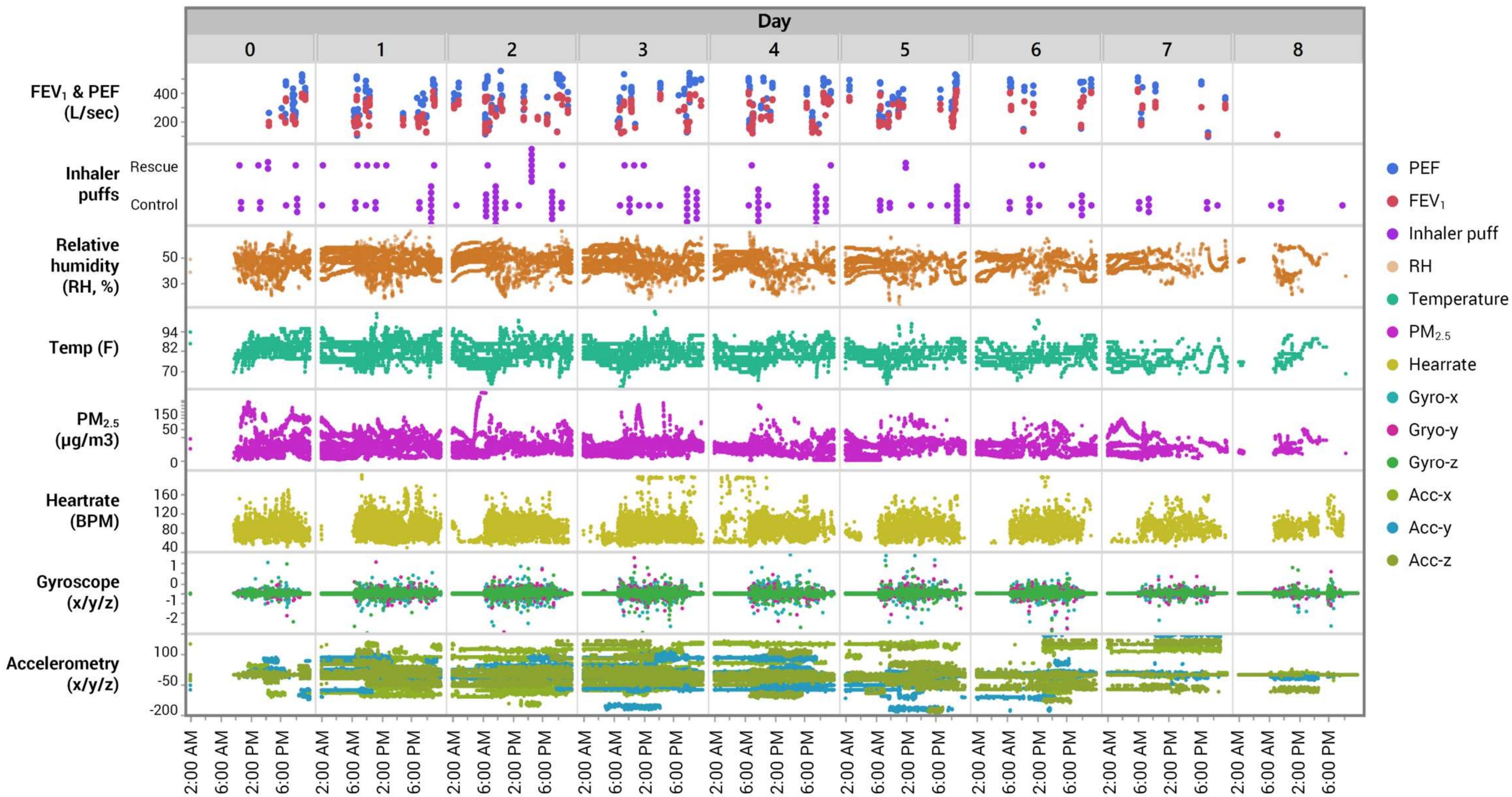
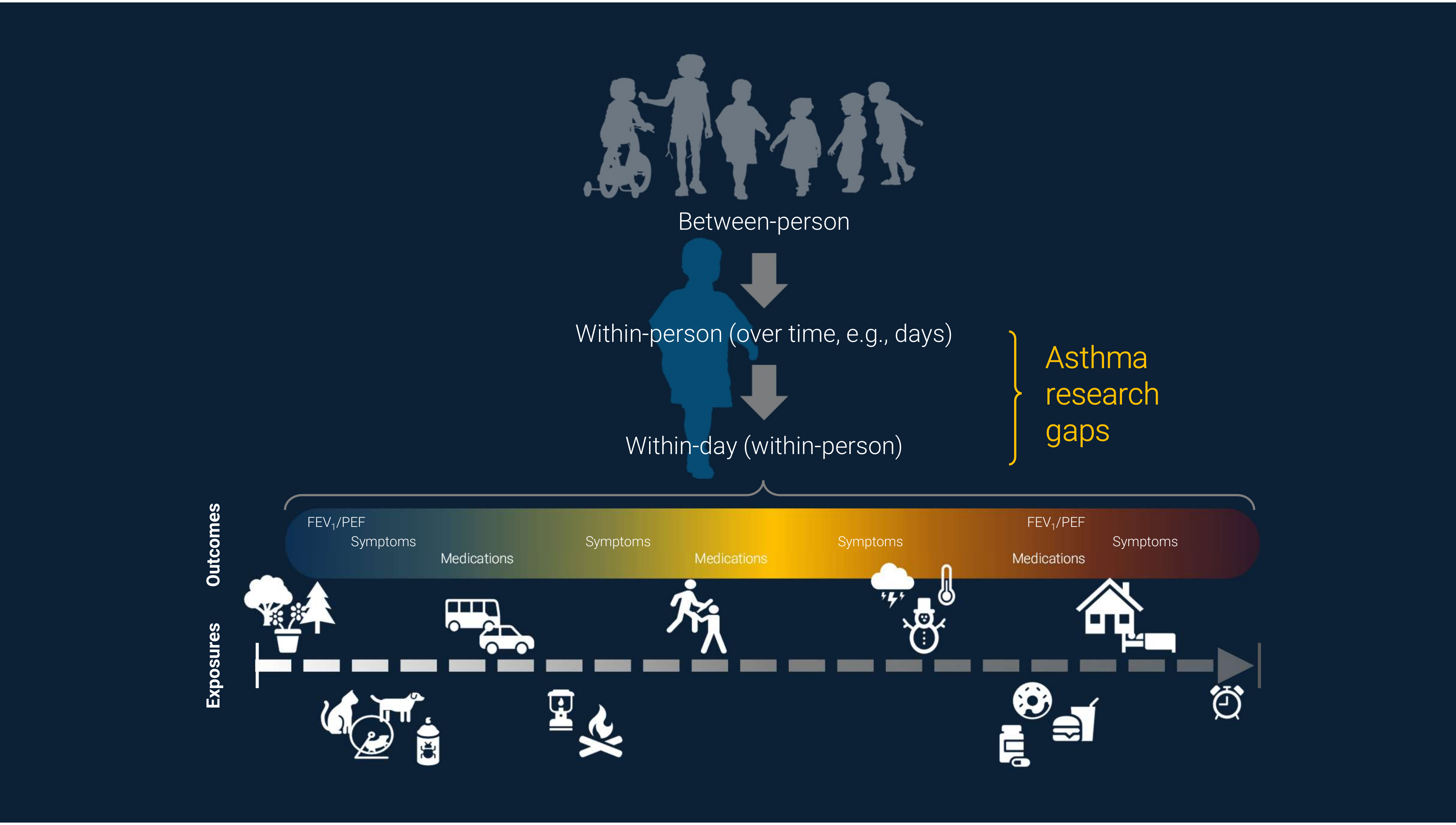


Figure 4. Plots showing the highly time-resolved nature of continuous and intermittent data streams across all subjects. Information on personal environment ($PM_{2.5}$, relative humidity, temperature), motion and physical activity (accelerometry, gyroscopy, heart rate), medication usage (rescue/control inhalers), and spirometry (FEV_1, PEF) are illustrated. FEV_1: forced expiratory volume in 1 s; PEF: peak expiratory flow.

Bui et al, *JAMIA Open*, 3(2), 2020



Between-person
Within-person (over time, e.g., days)
Within-day (within-person)
Asthma research gaps
Outcomes
Exposures
FEV1/PEF
Symptoms
Medications
Symptoms
Medications
Symptoms
FEV1/PEF
Medications
Symptoms

Informatics Platform for Sensor-Based Studies

Real-Time, Wireless, High-Resolution

Los Angeles PRISMS pediatric asthma study

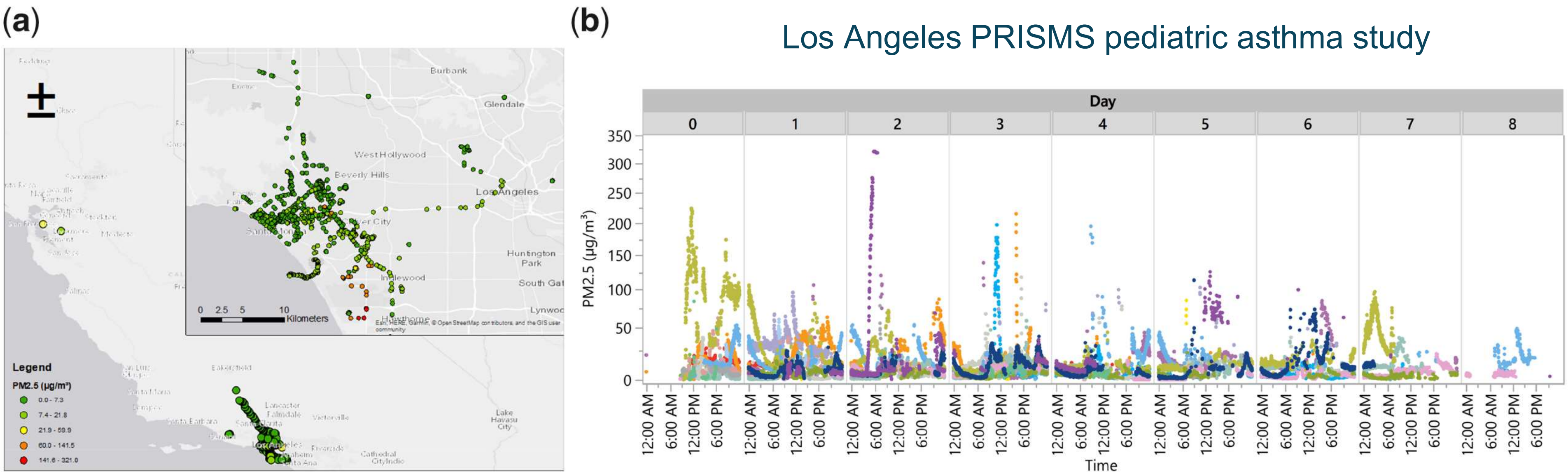
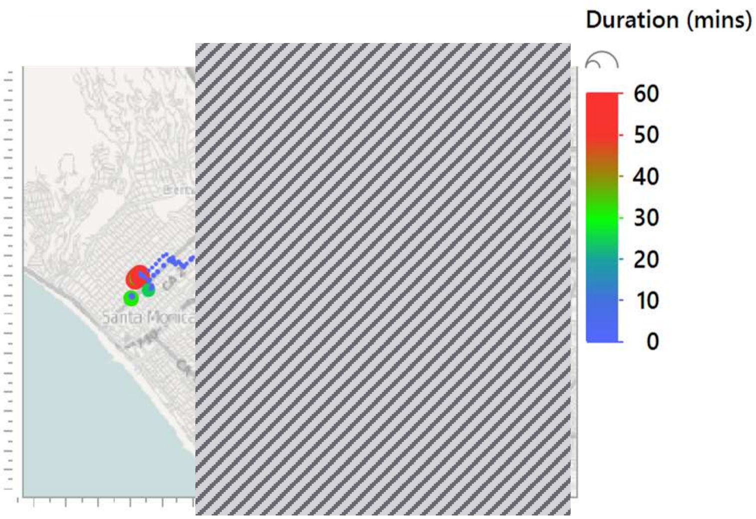


Figure 5. Examples of data collection from BREATHE. (A) Map of GPS trajectories across all subjects, correlated with 1-min $PM_{2.5}$ concentrations. (B) Temporal variation in personal $PM_{2.5}$ concentrations colored by subject. BREATHE: Biomedical REAl-Time Health Evaluation; GPS: global positioning system; PM: particulate matter.

Bui et al, *JAMIA Open*, 3(2), 2020

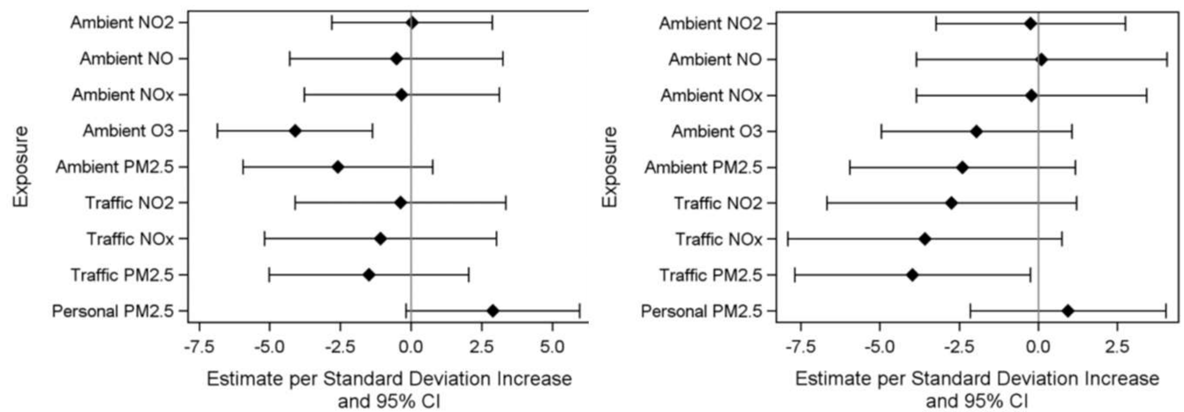
https://youtu.be/6y0tzsfApw4

Daily and Sub-Daily Health Analyses



Spatiotemporally resolved exposure measurements and models

Morning FEV_1 and PEF Lung Function Outcomes



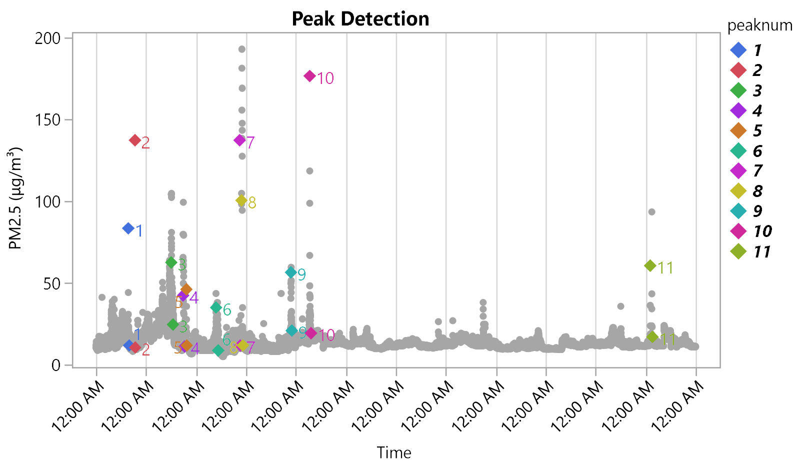
Hua Hao, PhD

Yisi Liu, PhD

Roxana Khalili, PhD

Hao H et al., Daily Associations of Air Pollution and Pediatric Asthma Risk Using the Biomedical REAl-Time Health Evaluation (BREATHE) Kit. *IJERPH* . 2022.

Context-Sensitive Data Collection and Just-in-Time Adaptive Interventions



Item
Were you near any of the following just before the phone alert appeared?

Response Choices
Traffic (cars, buses or trucks)
Cigarette smoke
Vaping/e-cigarette vapor
Cooking or barbequing (BBQ)
Lit fireplace (burning wood or gas)
Space heater (burning fuel)
Burning candles or incense
Other smoke

GeoAI'19, November 5, 2019, Chicago, IL, USA Yang and Jankowska

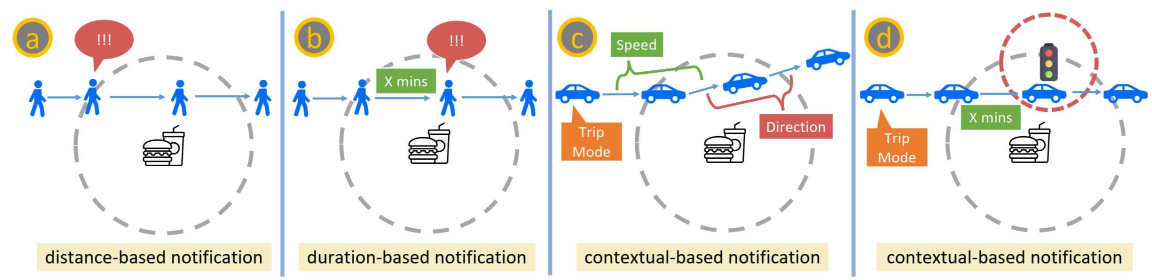


Figure 1: JITAIs using geo-fencing and time lapse for message triggering (a and b) compared to a GeoAI JITAI that includes spatio-temporal context for more targeted intervention.

Figure from Yang and Jankowska. Contextualizing Space and Time for GeoAI JITAIs (Just-in-Time Adaptive Interventions). *GeoAI'19*, Nov 5, 2019.

Two Approaches to Personal Monitoring

"Classic"

MADRES Environmental Health Disparities Center

- Research-grade personal monitors
- Time lag to access and interact with data
- Higher power consumption possible for GPS tracking
- Often limited to shorter deployments, high burden
- ↓ interactive, ↓ chance to bias data collection
- Fixed, static protocol

"Novel"

Los Angeles Pediatric Research Using Integrated Sensor Monitoring Systems (PRISMS) Center

- "Low-cost" air sensors, wearables
- Real-time, wireless informatics platform
- Power optimization for GPS (and other sensors in ecosystem)
- Longer deployments if well designed (usability)
- ↑ interactive, ↑ potential bias (esp. missingness)
- Dynamic, evolving parameters

Conclusions

- Advances in personal monitoring are allowing scalable, highly *personalized* and resolved assessment within activity spaces
  - Capture mobility, time-activity patterns, and μenv'al exposures
  - ↓ exposure measurement error
  - ↑ understanding of specific sources and mixtures
- Personalized exposure and health risk models and just-in-time, contextually smart interventions
  - New paradigm for "precision" health risk communication
  - Important privacy and ethical considerations

Thank You

- Mentees
  - Karl O’Sharkey, Hua Hao, Yan Xu, Li Yi, Yougeng Lu, Jeremy Yu, Leon Zha, Roxana Khalili, Yisi Liu, Lianfa Li, Lisa Valencia, Jane Cabison, Mariam Girguis, and more…
- Collaborators
  - USC: Carrie Breton, Theresa Bastain, Shohreh Farzan, Genevieve Dunton, Jill Johnston, John Wilson
  - UCLA: Alex Bui, Rose Rocchio, PRISMS team
  - STI: Fred Lurmann, Nathan Pavlovic, Crystal McClure
  - And many more…
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  - Los Angeles PRISMS Center, NIBIB U54EB022002 (Bui)
  - CTSI UL1TR001855 pilot (Habre and Mason)
  - NIEHS R01ES027409 (Breton)

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https://arcg.is/1y8KHn

NIEHS Workshop Series starts July 22nd !

Accelerating Precision Environmental Health: Demonstrating the Value of the Exposome