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Development of wearable environmental and physiological sensors

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Funding and Support:

- National Institute of Environmental Health Sciences Grant R01-ES023349 (Peden)
- NSF Nanosystems Engineering Research Center for Advanced Self-Sustaining Integrated Sensor Technologies (Misra)
- National Center for Advancing Translational Sciences 1-OT3-TR002020 "Carolina Biomedical Data Translator" (Ahalt)
- Environmental Protection Agency Cooperative Agreement CR 83578501 "Human Health Effects of Environmental Pollutants" (Peden)

Overview of the Project(s)

- To develop a wearable environmental sensor array that is self powered
  - Ozone (gas phase pollutants)
  - Relative humidity
  - Ambient temperature
  - Particulate matter
  - VOCs
- To develop wearable/portable physiologic sensor array that is self powered
  - Spirometry
  - Minute Ventilation (needed for pollutant dosing)
  - ECG, Pulse, Blood Pressure
  - Accelerometry
- To develop data query/analytic capabilities that allow for patient actionable analyses
  - Combining EMR, environmental data, SES data

ADVANCED SELF-POWERED SYSTEMS OF INTEGRATED SENSORS AND TECHNOLOGIES (ASSIST)

VEENA MISRA, PHD, NCSU

ASSIST'S VISION IS TO USE NANOTECHNOLOGY TO IMPACT HEALTHCARE AND MANAGE WELLNESS

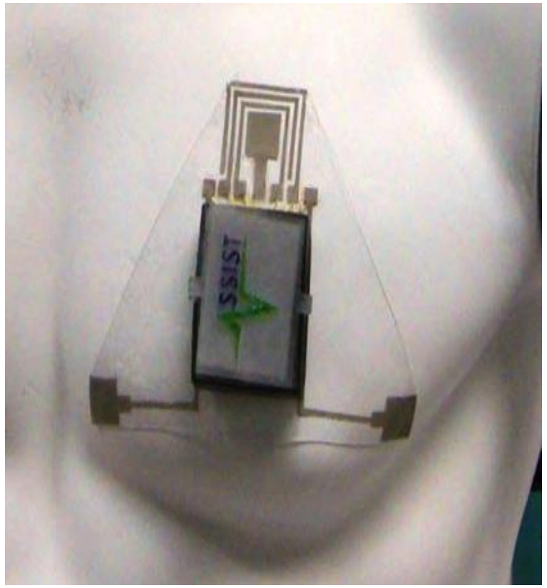
FUNDED BY NSF AND NIEHS, SUPPORTED BY EPA

EPA Human Studies Facility at UNC

1. Combustion particle chamber
2. Ozone/NO2 chamber
3. CAPS Chamber
4. Exercise Physiology Suite
   1. Spirometry (FEV1/FVC)
   2. Pneumotachometry (Ve)
   3. ECG telemetry
   4. Watts
   5. Blood Pressure
   6. Exercise ergometer
   7. Treadmill
5. Staff
   1. Physician-Scientists
   2. Exercise physiologist
   3. Respiratory Therapist
   4. Chamber Engineers

Asthma Management Wrist/Chest Platform

Total power consumption of less than 1milliWatt for wrist and chest platforms with multiple health and environmental sensors



Ozone, VOC, pulse, accelerometry, Temp/rH

ECG, microphone, pulse, accelerometry, skin impedance

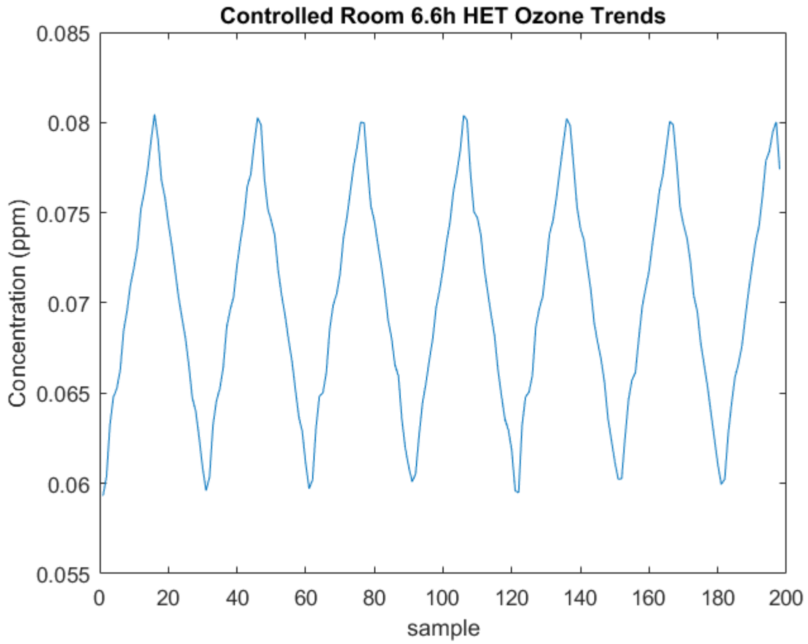
James Dieffenderfer, et al., "Low Power Wearable Systems for Continuous Monitoring of Environment and Health for Chronic Respiratory Disease", JBHI-00027-2016

Human biological responses to low level ozone: protocol design

- Double-blinded, placebo controlled crossover study comparing human responses low level ozone to clean filtered air
- Ozone level oscillated between 0.06 and 0.08 ppm (to test the ozone sensor, which also has to account for RH)
- No exercise (most ozone challenges use exercise)
- Physiologic measures included:
  - Lung Function
  - Respiratory Rate
  - Heart Rate and Heart Rate Variability
  - Blood pressure
  - Lipids, circulating neutrophils*
  - Still to be assessed, inflammation in nasal lavage fluid*

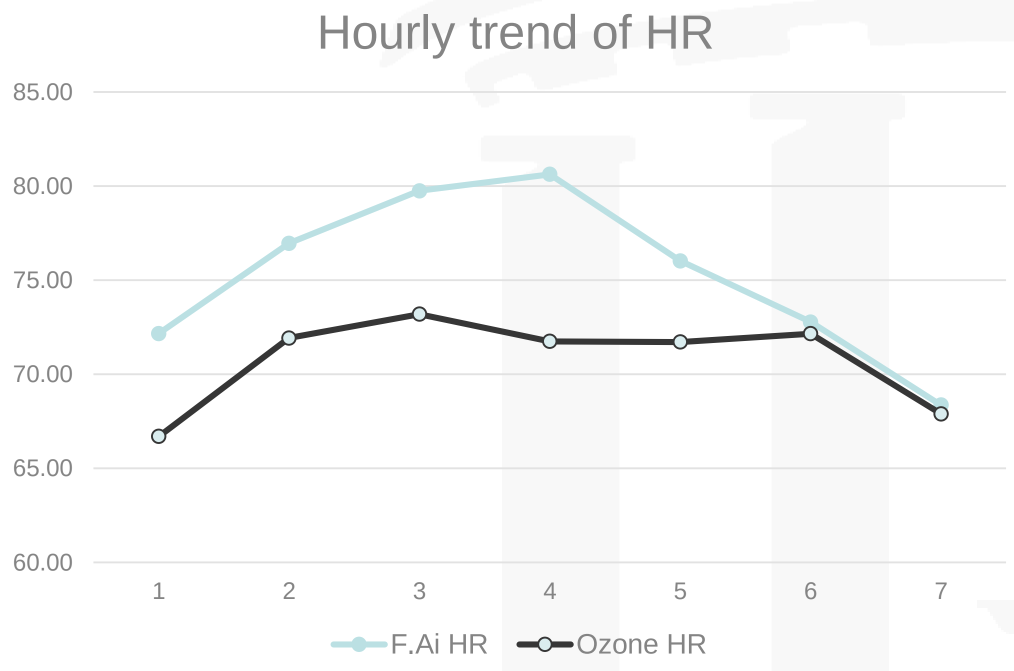
Ozone Monitoring Data

HET device ozone measurement



Shimmer device ozone measurement

ECG and HRV Analysis Results



Effects of Ozone:

- Heart Rate decreased by 6.17%
- The **HRV triangular index increased** between **6% and 13%** in the **first three hours** and then started to **decrease** between **9% and 15%** following 3 hours.
- Mean HRV triangular index decreased by 4.25%

Effects of Ozone on other parameters

- There were no significant changes in
  - **respiration rate** (first-day: 15, air: 15.1, ozone: 15.4 breaths per minute)
  - **body temperatures** (first-day: 36.4°C, air: 36.3°C, ozone: 36.5°C)
- Oxygen saturation (SpO2) decreased after ozone exposure but quantitative changes were not significant.
- **Blood pressure** increased immediately after the ozone exposure with reflecting the effects of ozone, compared with the filtered air exposure during the last 6 hours

	Exposure	Air	Ozone	Effect %
SpO2	1 hr	98.75	98.18	-0.58
	2 hr	98.64	98.18	-0.46
	6 hr	98.31	98.09	-0.23
Systolic BP	1 hr	118.81	117.45	-1.14
	2 hr	123.45	119.36	-3.31
	6 hr	116.69	123.00	5.41
Diastolic BP	1 hr	78.25	76.64	-2.06
	2 hr	73.00	76.36	4.61
	6 hr	72.75	78.45	7.84

- **Neutrophils** increased by 3.11% under ozone exposure.
- Another major increase is seen at **basophils**
- **Monocytes** decreased from 7.83 to 7.70 with filtered air exposure and raised up to 8.30 with ozone.

Overall (preliminary conclusions)

- Wearable sensors allowed for assessment of personal ozone exposure and a number of real time changes in human physiology
- Ambient levels of ozone **without** exercise caused
  - Decreased heart rate (?increased vagal tone)
  - Decreased HRV (increased vagal tone, generally thought to be maladaptive)
  - Increased blood pressure
  - Increased systemic inflammation as reflected in increased PMNs

The NCATS Biomedical Data Translator Program: ~200 team members, ~30 institutions

Green
UNC/RENCI
Cedar Grove Institute for Sustainable Communities

Orange
Oregon Health & Science University
Oregon State University
Oregon State University
Johns Hopkins University
Scripps Research Institute
Mayo Clinic
Jackson Laboratory
Berkeley National Laboratory
Delphinai Corporation

Red
Columbia University
Maastricht University
University of Alabama, Birmingham

Blue
St. Jude Children's Research Hospital
University of California, San Diego
Institute for Systems Biology
University of Montreal

Grey
The Broad Institute

Purple
NIH/NCATS

Gamma
UNC/RENCI
CoVar
Berkeley National Laboratory
Delphinai Corp. Informatics
Oregon Health & Science University
NIEHS

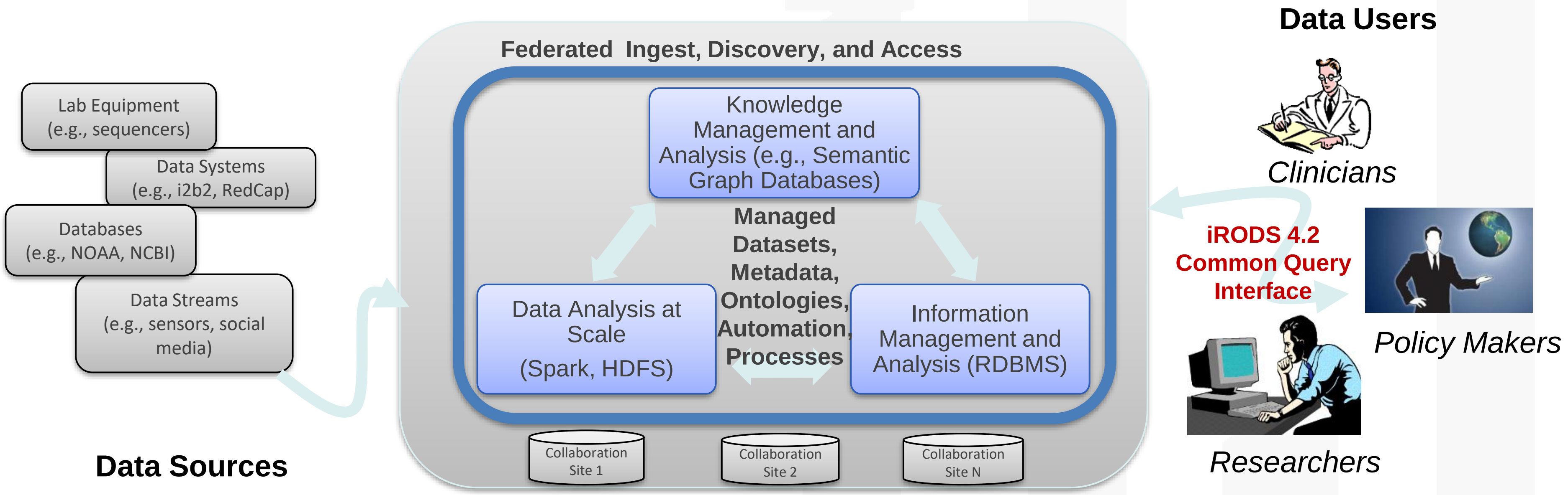
Infrared
Stanford University

Alpha
Scripps Research Institute
University of Alabama, Birmingham

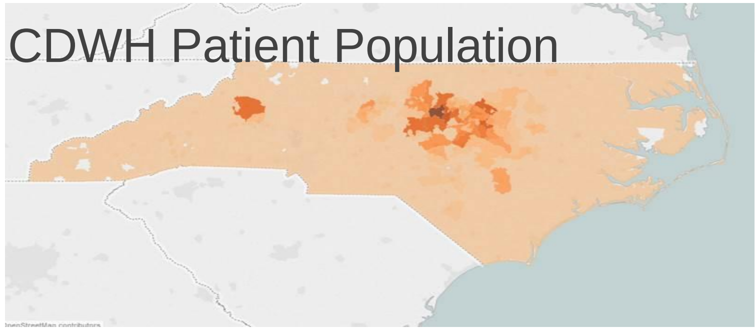
X-ray
Institute for Systems Biology
Oregon State University
University of Washington
Ohio State University
Simon Frasier University

Ultraviolet
The Broad Institute

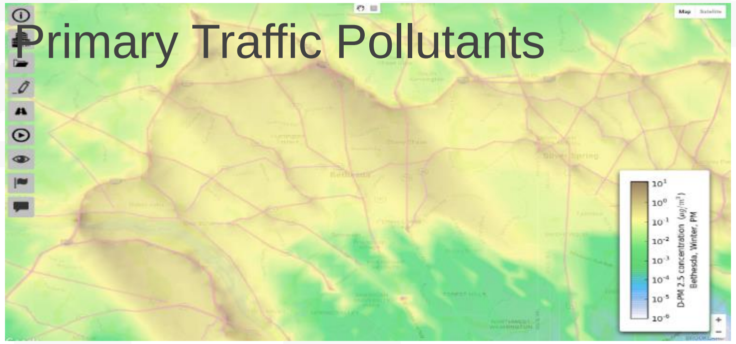
Integration Approach: BDT Data Incubator



Example of Data Sources:

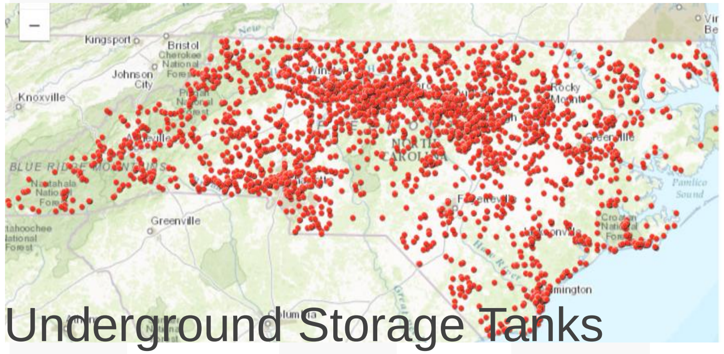


CDWH Patient Population



Primary Traffic Pollutants

Hazardous Waste Sites



Underground Storage Tanks

Demonstration Use Case: Asthma


shortness of breath

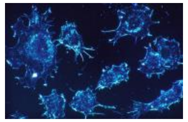
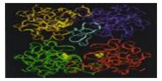
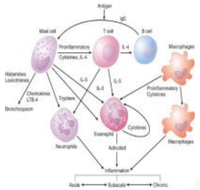
wheezing

stridor

eosinophilia

+ airborne allergen panel

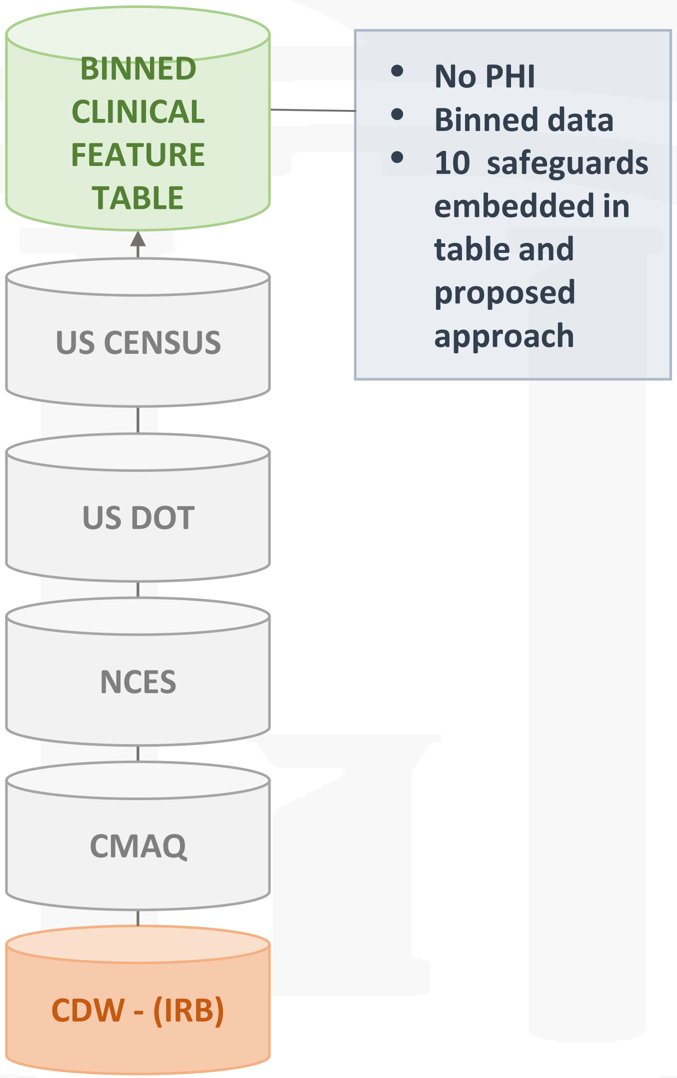
reduced lung function

Patient JD:
12 years old
Black
Male
Durham, NC 27701
Parents smoke
Asthma, hay fever
Mild increase IgE
Normal chest X-ray
Normal lung function
Albuterol inhaler
Oral corticosteroid bursts >3 times/y
>2 ED visits/y, usually during fall & summer
High PM2.5 exposure
High ozone exposure
Parent unemployed
Parent < HS education
Household <50 m from bypass

Binned Clinical Feature Tables

- Beginning with IRB approval and a secure computing workspace, integrate clinical data with:
  - Chemical airborne exposures data (CMAQ)
  - Roadway exposures data (US DOT)
  - American Community Survey data on household income, educational attainment, etc. (US Census)
- Integration requires patient geocodes, dates, and identifiers
- After integration, data are de-identified according to HIPAA Safe Harbor (Safeguard #1)
- Feature variables are recoded or binned to further protect against unintentional leakage of sensitive data (Safeguard #2)
- Only aggregated counts of patients or visits are presented to users (Safeguard #3)



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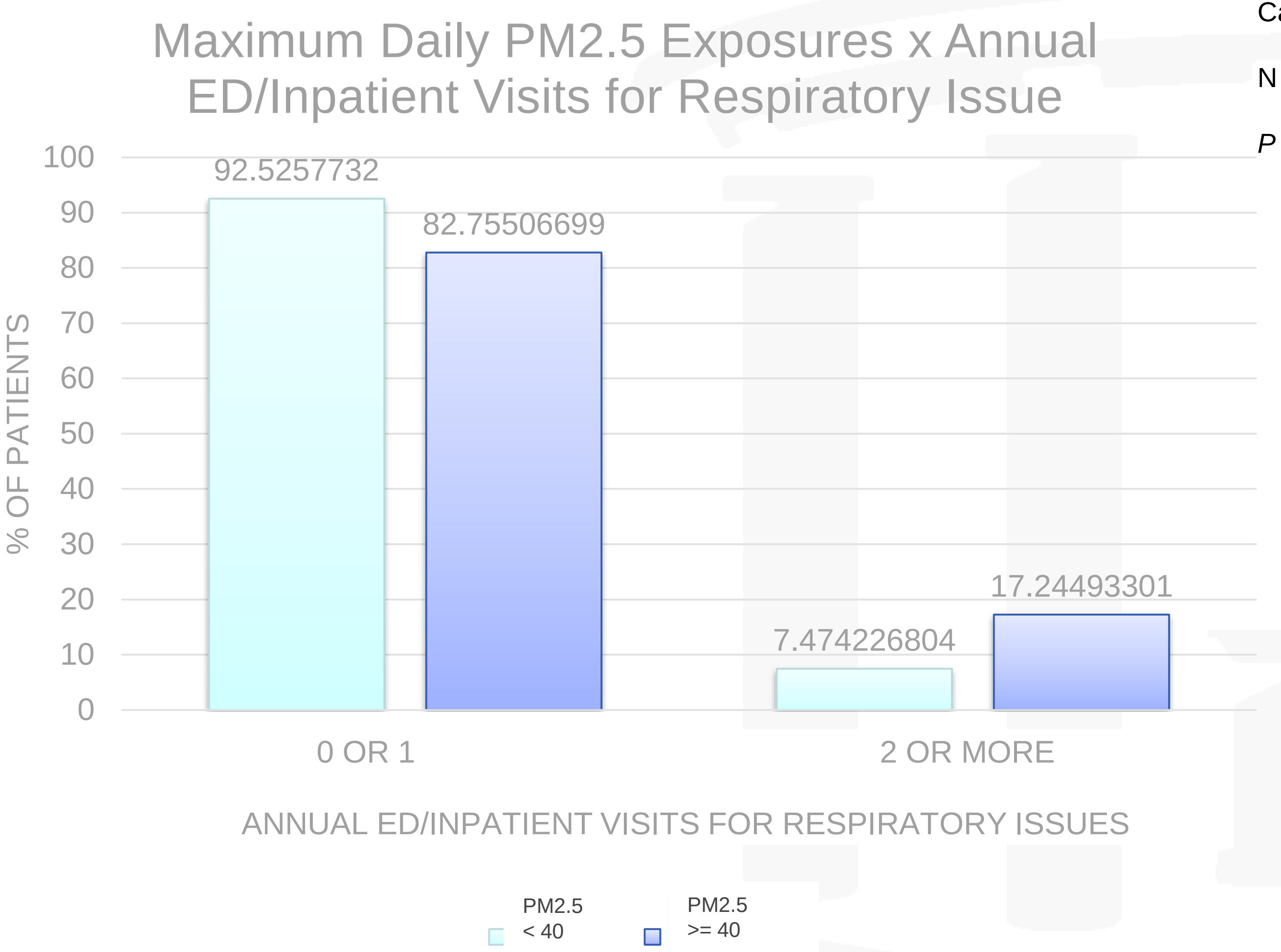
Calendar Year 2010

N = 23,093

P < 0.0001



Summary

- **Multi-disciplinary science and action**
- To provide useful health and environmental monitoring an array or stationary, portable and wearable monitors will be requited
- Integration of personal and regional data with electronic health data will be needed
- The goal is to ultimately facilitate predictive modeling to guide personal, medical and societal interventions to mitigate environmental impacts on human health
- Diseases shown to be impacted by ambient air pollutants include: asthma, pneumonia, congestive heart failure, sudden cardiac death, hypertension, autism, cognition, depression.