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Using lower cost sensors to understand household energy use and its implications on pollution exposure and health

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on behalf of
Tracy Allen, Ilse Ruiz-Mercado, Rufus Edwards, Zohir Chowdhury, Michael Johnson and Berkeley Air Monitoring Group, Kirk R. Smith, and the Household Energy, Health, and Climate Research Group

HOUSEHOLD ENERGY, HEALTH, & CLIMATE RESEARCH GROUP
UNIVERSITY OF CALIFORNIA, BERKELEY

By the numbers

~3 billion people use solid fuels for cooking

While the proportion of the population using these fuels is decreasing, the absolute number has remained relatively constant over the past 30 years

Bonjour et al, who.int, and State of Global Air 2018

Global distribution of solid fuel use

State of Global Air 2018

PALWAL
Haryana, India


SAN LORENZO
Guatemala

KINTAMPO
Ghana

Kharelthok
Nepal

Addis Ababa
Ethiopia

Khargiakh

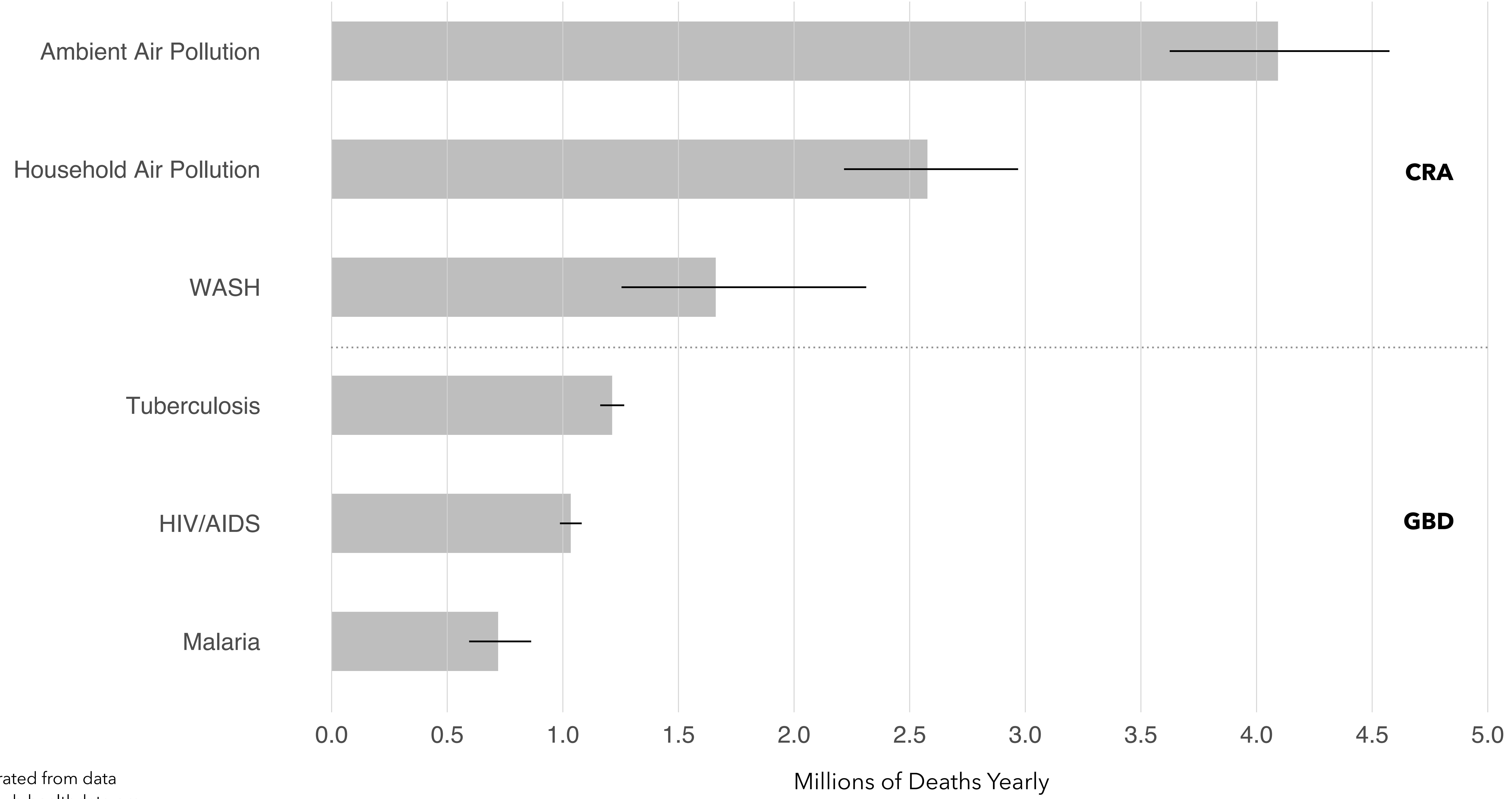
Ladakh, India

By the numbers

3-4 million deaths yearly from exposure to $PM_{2.5}$ arising from the combustion of solid fuels

Bonjour et al, who.int, and State of Global Air 2018

IHME Global Burden of Disease 2016



Generated from data
at vizhub.healthdata.org

What parameters are poorly quantified?

What can we measure objectively with sensors?

How often and when do we need to measure?

Ventilation

Stove Use

Time-Activity

Proximity

Location

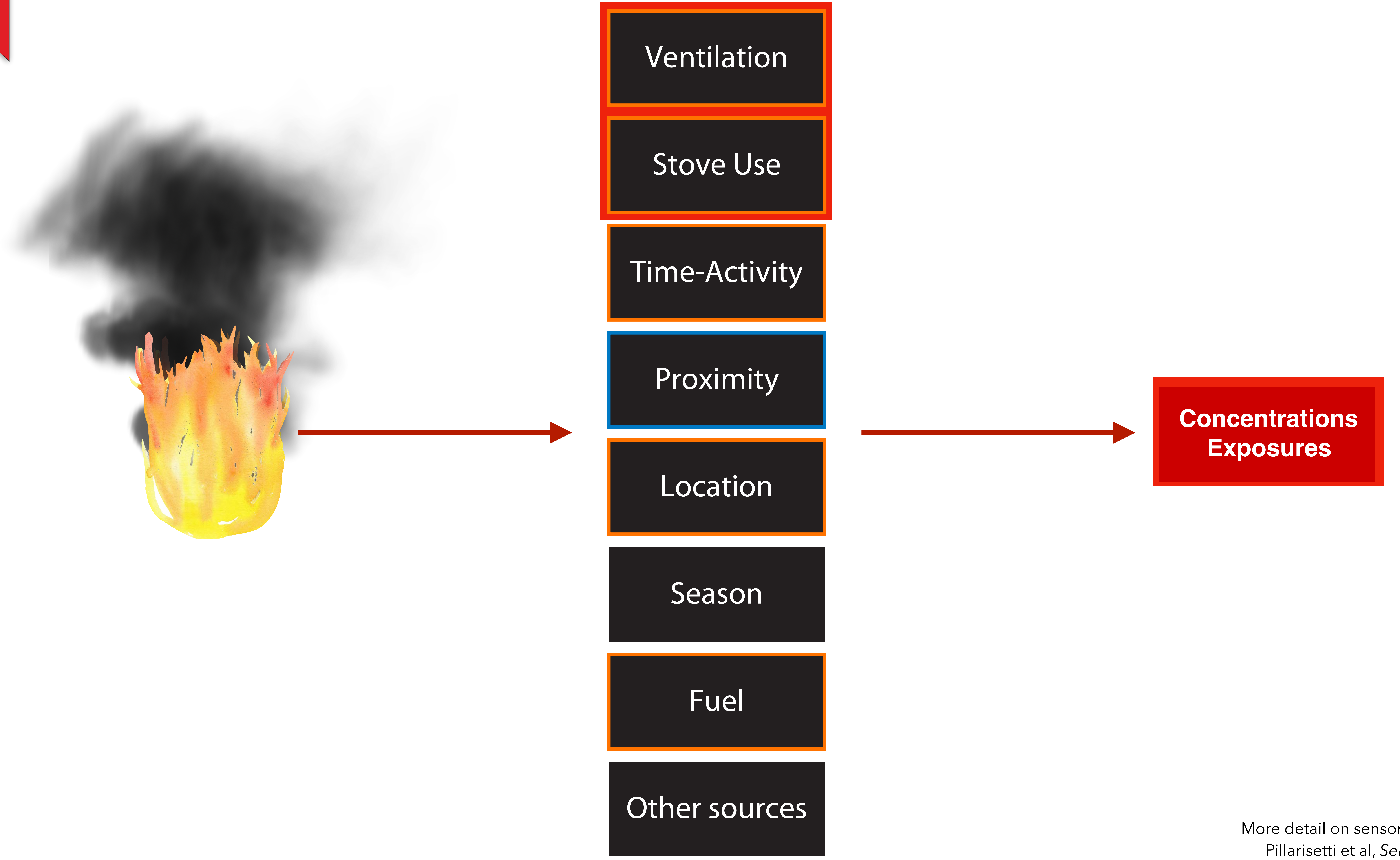
Season

Fuel

Other sources

Concentrations Exposures

More detail on sensor systems in Pillarisetti et al, *Sensors*, 2018



More detail on sensor systems in
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The challenge of sensing in LMICs

Off-the-grid — batteries required

Robust to harsh conditions, toxic and corrosive gases

Wide-sensing range – very clean to very dirty (peaks at 120 mg/m^3 not uncommon)

Easy-to-service clean

The UCB-PATS
Conceptualized in 2000-2001

Work started in 2002

Published in three rigorous papers: a theoretical discussion, a laboratory evaluation, and a field evaluation

Litton, Aerosol Science and Technology, 2004
Edwards, J. Air & Waste Manage. Assoc, 2006
Chowdhury, J of Ev. Monitoring, 2007

Ideal for HAP field studies

Low-power consumption

50 μg/m³ - 120 mg/m³

Robust, easy to clean and service

UCB-PATS used in dozens to hundreds of studies around the world

~500 USD

PATS+

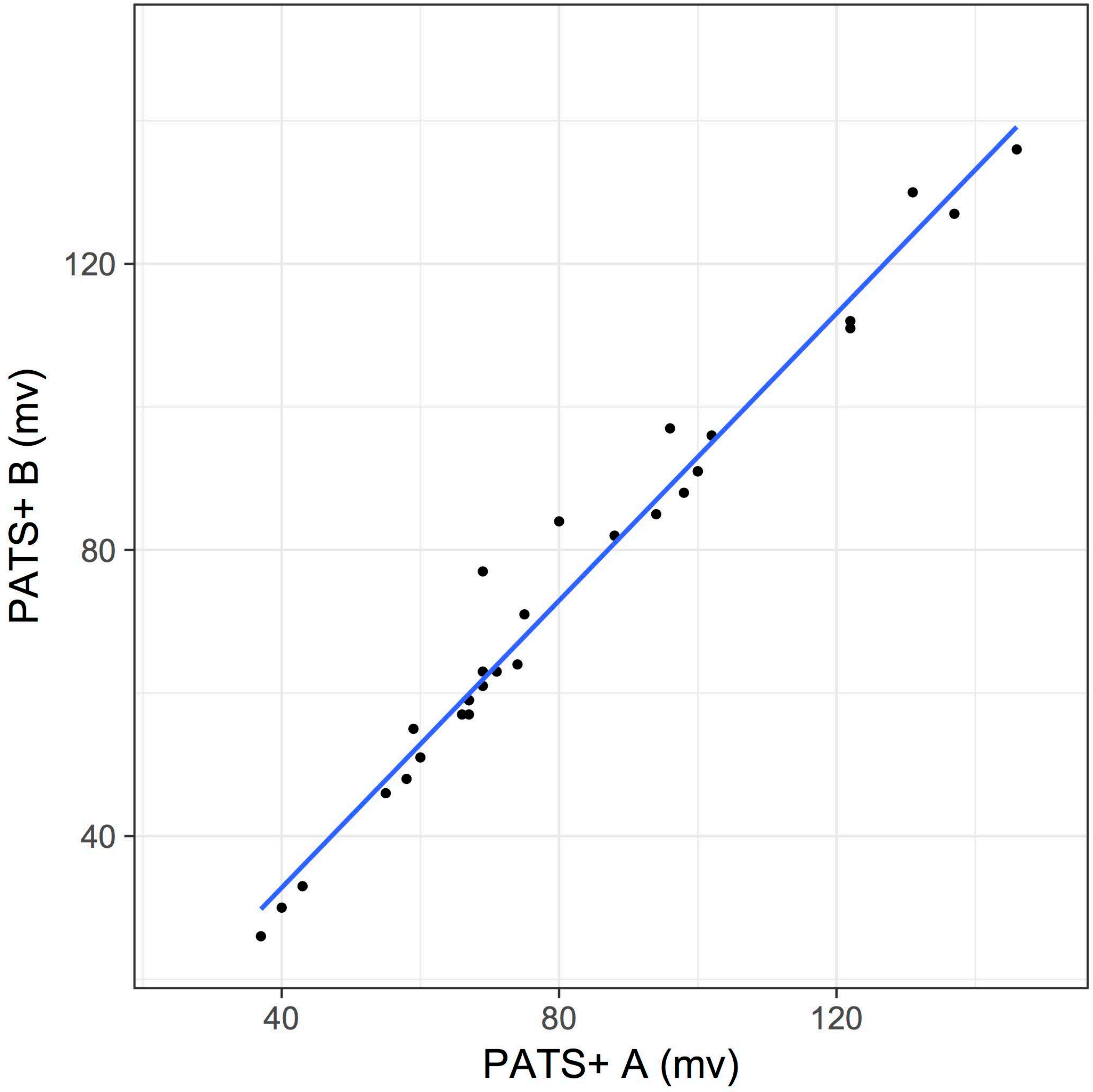
Wide dynamic range
10µg/m3 to 50mg/m3

Modern microelectronics
USB, SD card

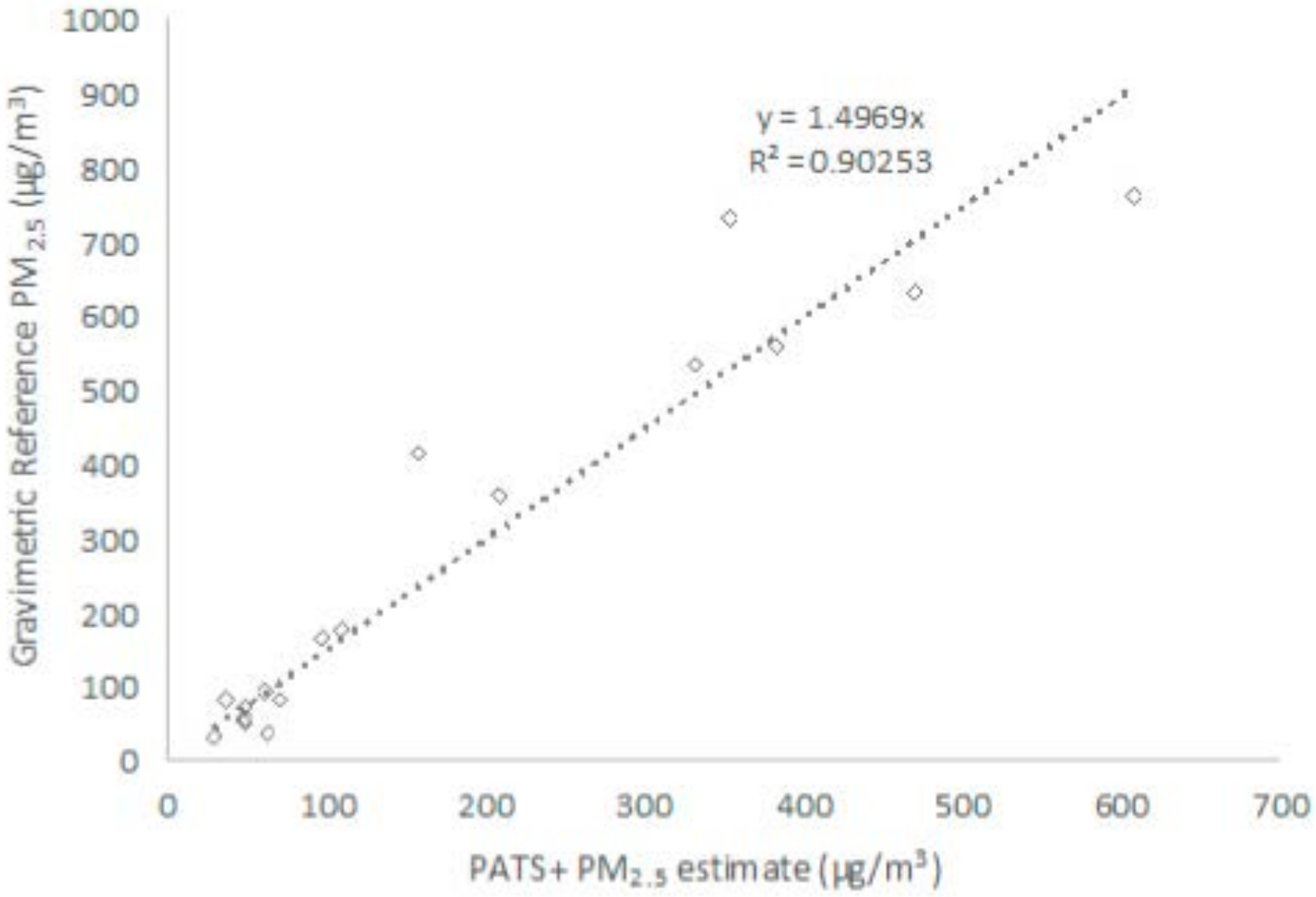
Long-battery life - ~48h as pictured; 72+h with new design


BERKELEY AIR
MONITORING GROUP
PATS+CO
Battery
BERKELEY AIR
MONITORING GROUP
CO Sensor
PM Sensor

Consistent response between devices



Strong correlation with gravimetric reference methods across a broad range of concentrations



Measuring temperature as a proxy for appliance usage
The Stove Use Monitoring System (SUMS)

Not to scale

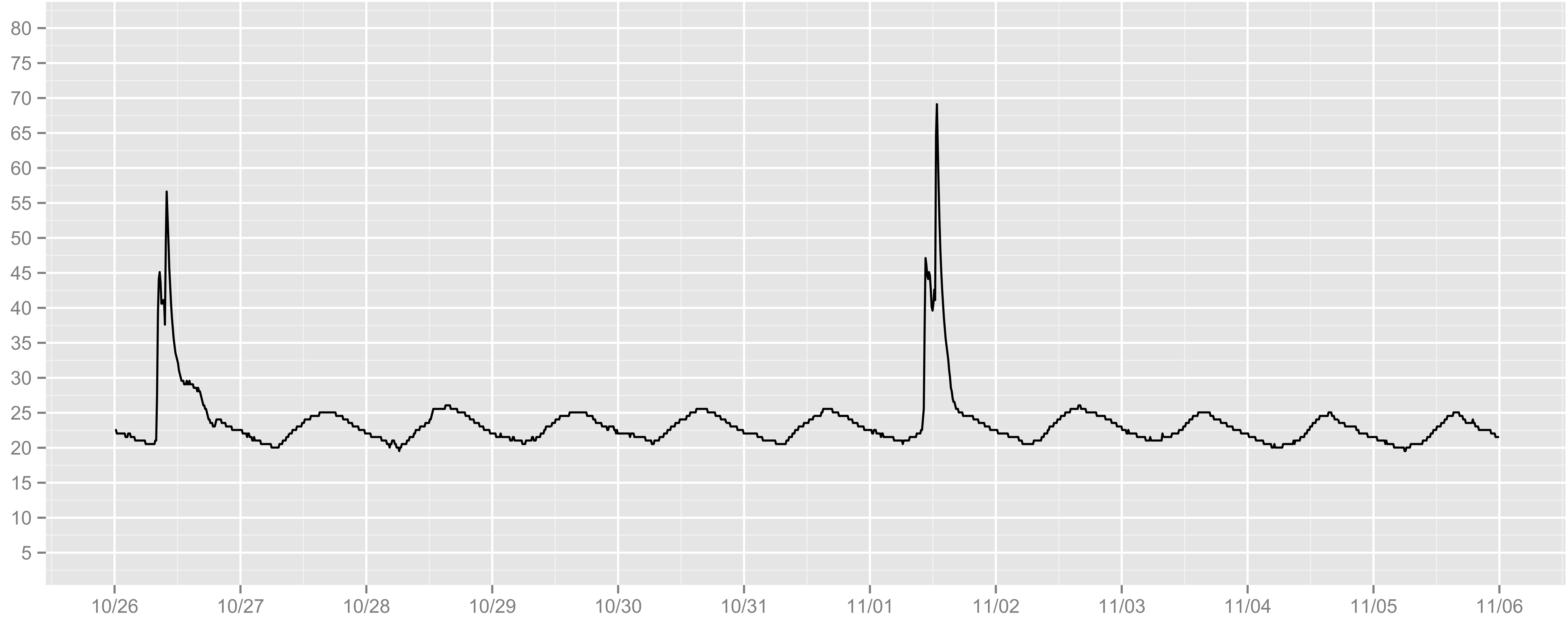
Data-logging thermometers

Variety of “flavors” — the one pictured here is a Maxim iButton

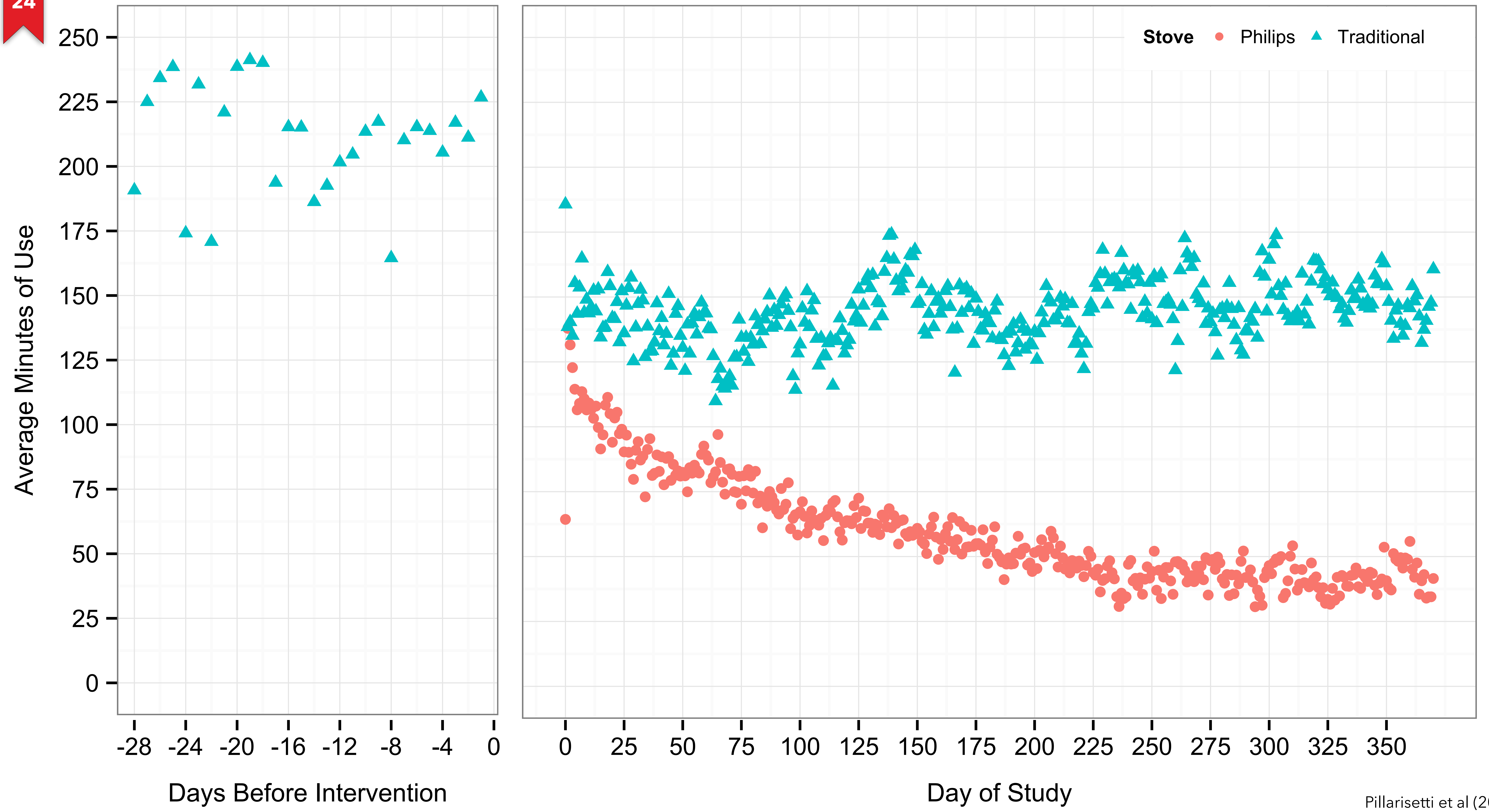
More recently, use of small, bluetooth enabled thermocouples — Geocene Dots

Mukhophadyay, Sambandam, Pillarisetti*, et al 2012

SUMs Data and Processing



Pillarisetti et al (2014)
Environmental Science & Technology



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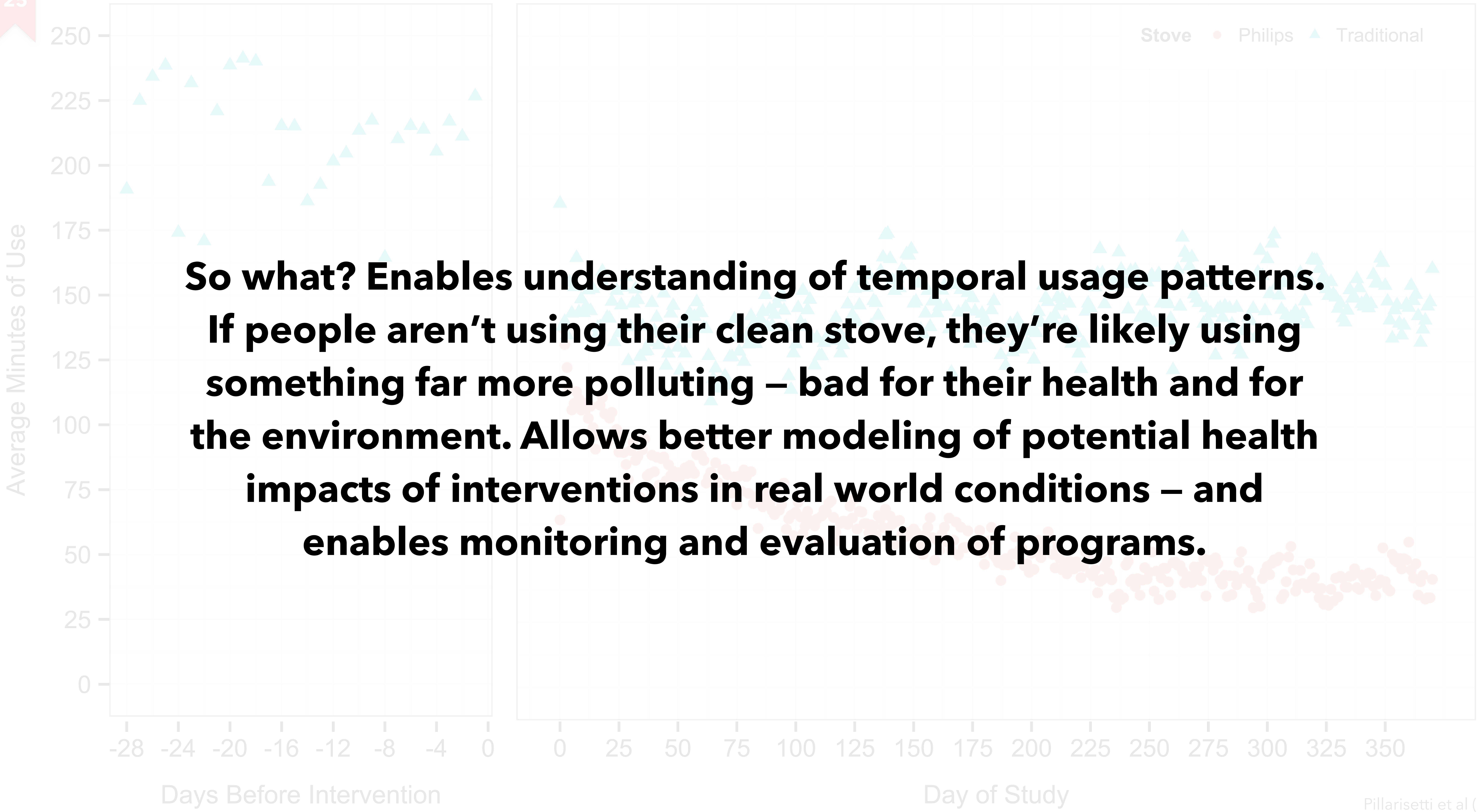


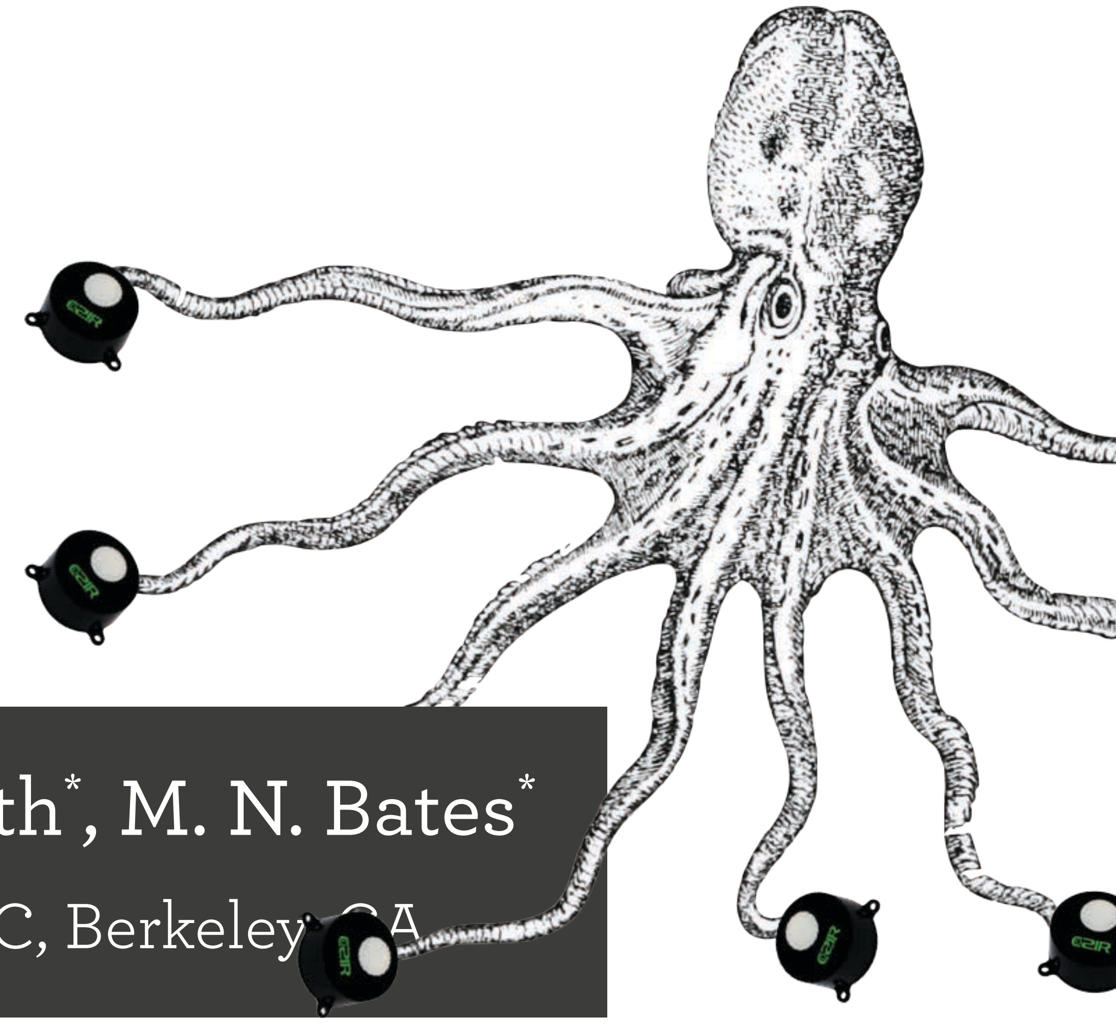
So what? Enables understanding of temporal usage patterns. If people aren't using their clean stove, they're likely using something far more polluting — bad for their health and for the environment. Allows better modeling of potential health impacts of interventions in real world conditions — and enables monitoring and evaluation of programs.

Pillarisetti et al (2014)
Environmental Science & Technology

A LOW-COST, CARBON DIOXIDE MONITORING SYSTEM FOR ESTIMATING HOUSEHOLD AIR EXCHANGE RATES

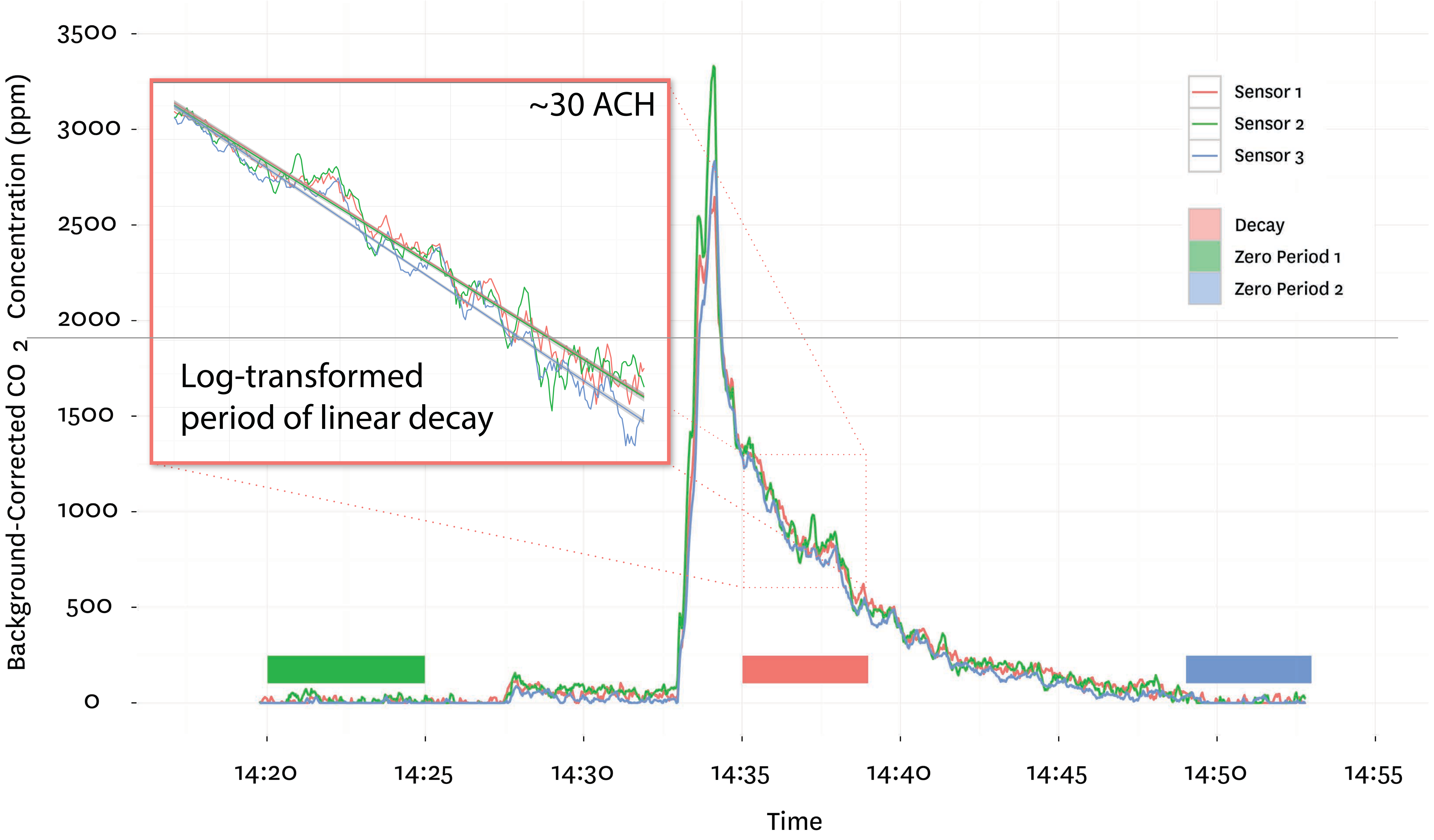
A. Pillarisetti[*], N. L. Lam[*], A. Pokhrel[*], L. D. Hill[*], T. Allen[#], B. Kunwar[°], B. Pandey[°], S. Thapa[°], T. R. Sijali[°], K. R. Smith[*], M. N. Bates[*]

[*]University of California, Berkeley, Berkeley, CA, [°]Institute for Social and Environmental Research-Nepal, Chitwan, Nepal, [#]EME Systems, LLC, Berkeley, CA



ARMS consists of a data-logger, two to four non-dispersive infrared CO_2 sensing arms, protocols for sensor placement and tracer gas release in households, and data analysis tools.

Sample ARMS trace from a single measurement period in a single kitche



Large dataset from Nepali Homes

- 4300 samples in total
- Very reliable system – 0.5% failure rate due to either human or sensor error
- Final dataset now includes 4280 files, consisting of 12800 valid CO_2 measurements from 1745 homes (an average of 3 sensors/file)

Count
2000
1000
0
0
100
200
300
Air Changes per Hour
COMMON
KITCHEN
LIVING


Morning
Afternoon
1500
1000
500
0
0
100
200
300
0
100
200
300
Count
Air Changes per Hour
COMMON
KITCHEN
LIVING

Can we opportunistically measure ventilation rates?

- In a subset of the ~1800 households we measured ventilation in, we also placed 48 hour CO and PM sensors
- How well do ventilation rates estimated from the decays of these pollutants in the evening match ventilation rates from ARMS?
- What predicts our estimated ACHs? Room volume, occupancy, number of windows, doors, size of eaves, etc?
- How well do estimates of ACH explain variability in models of PM2.5 concentration and exposure?

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