

# Household air pollution health impacts: current evidence across different sources

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*Professor of Global Environmental  
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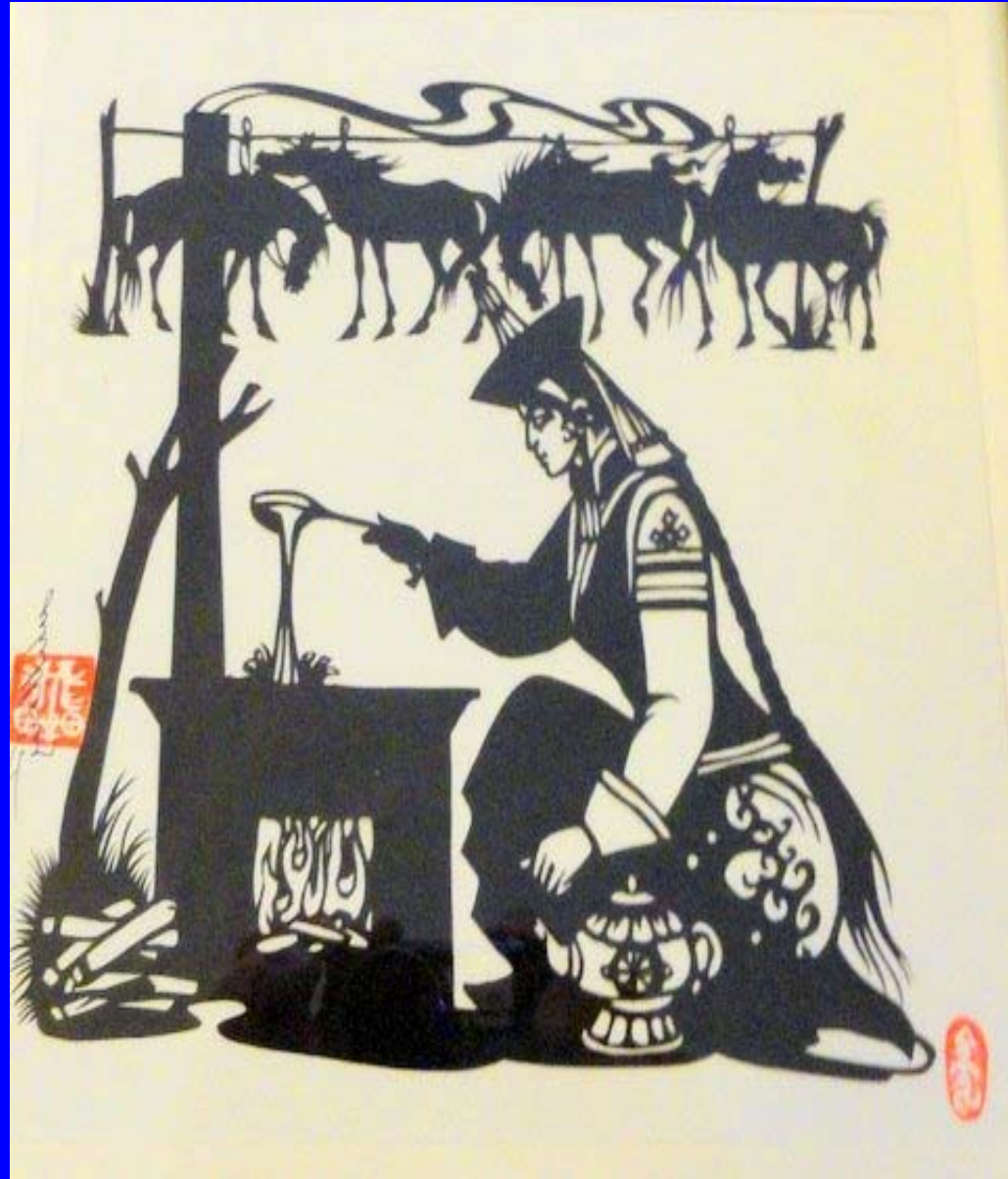
*University of California, Berkeley*

**Workshop on Decreasing Air Pollution  
Emissions from GER Districts**

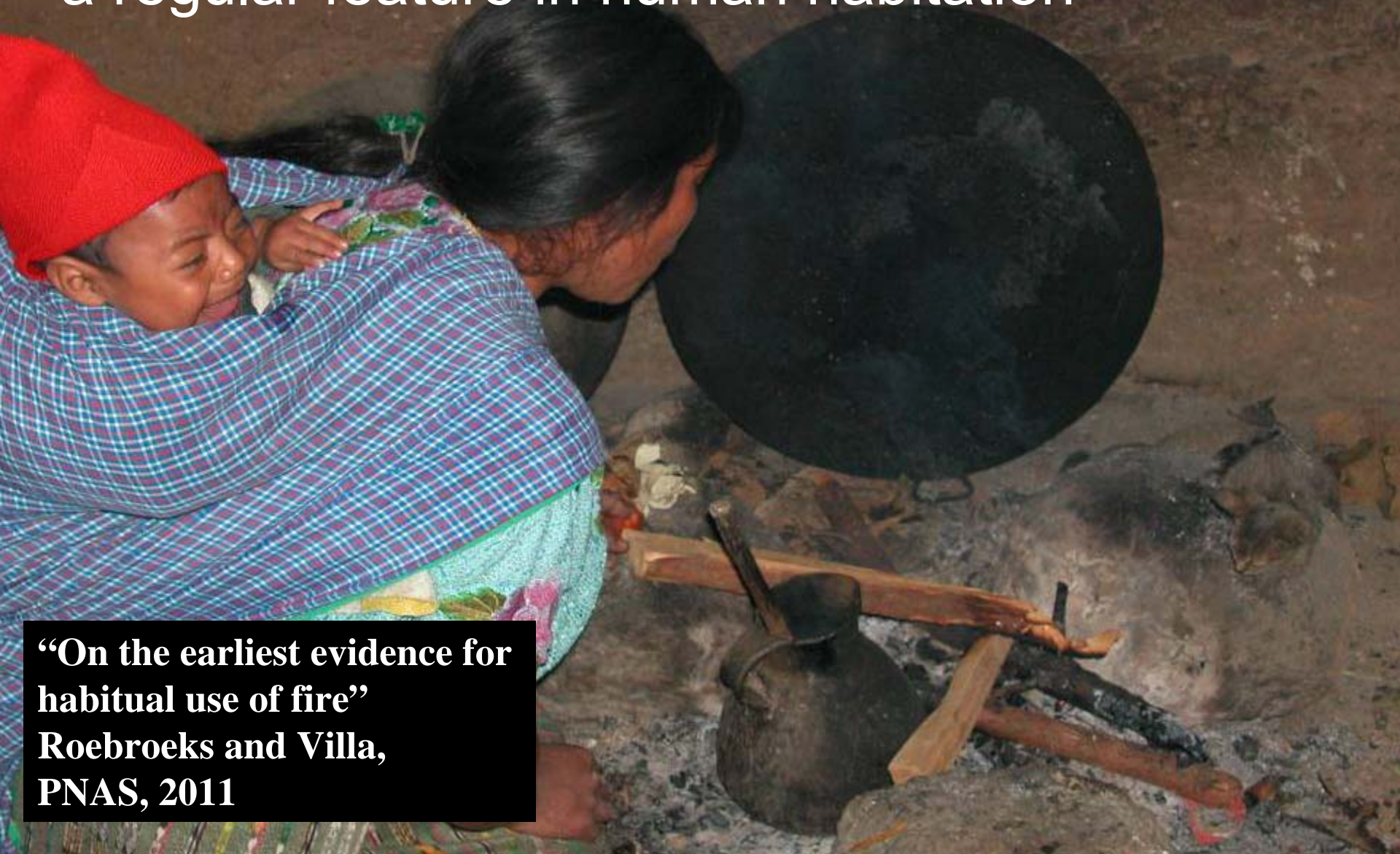
**Ministry of Health and  
Ministry of Mineral Resources  
and Energy**

**Ulaanbaatar, Mongolia**

**Oct 6, 2011**



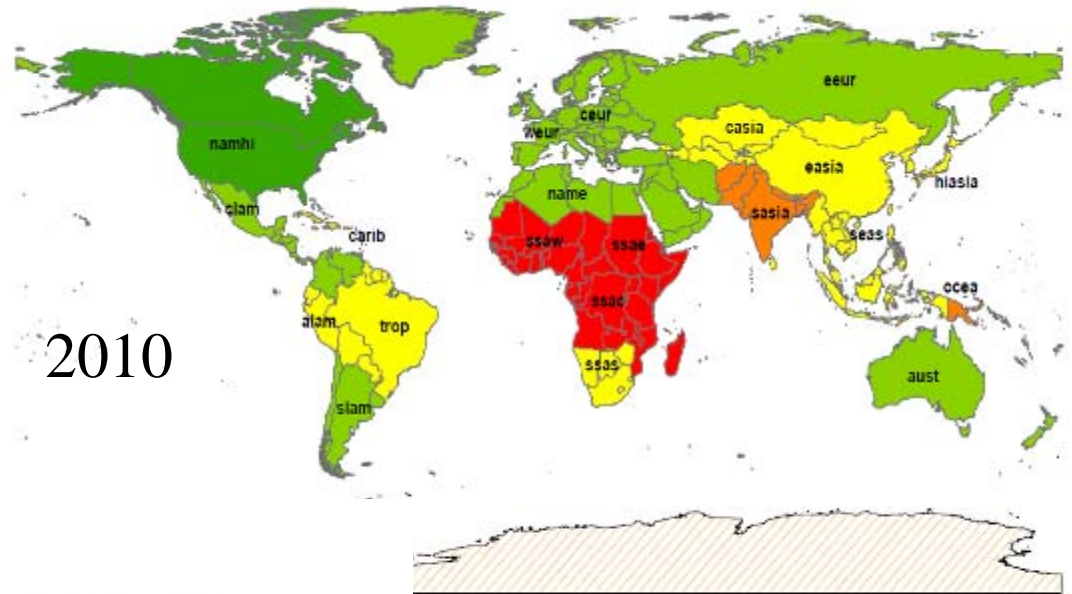
300-400 thousand years ago, hearths became  
a regular feature in human habitation



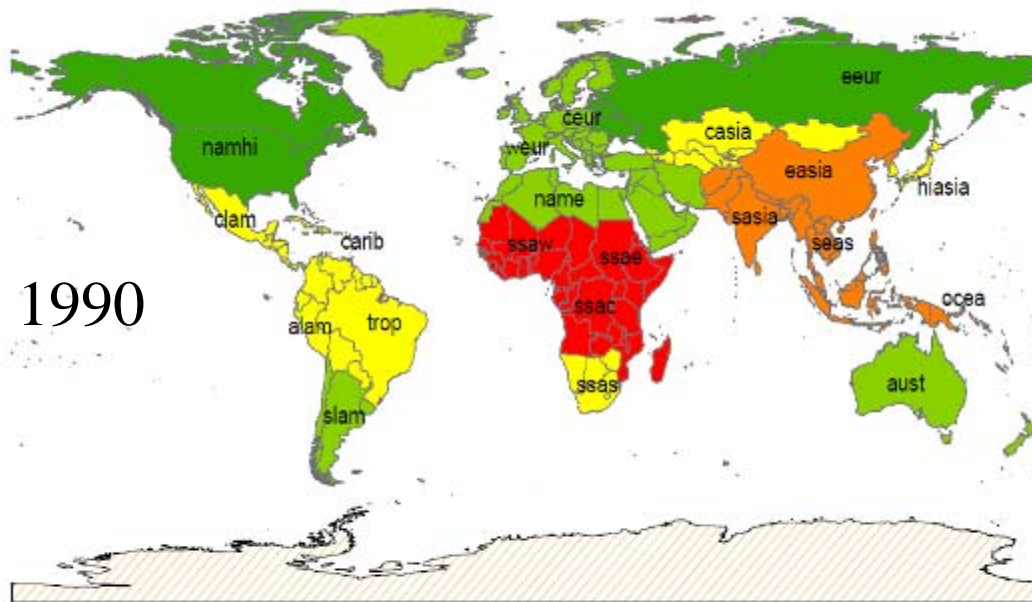
**“On the earliest evidence for  
habitual use of fire”  
Roebroeks and Villa,  
PNAS, 2011**

# Households using biomass or coal to cook

2010



1990

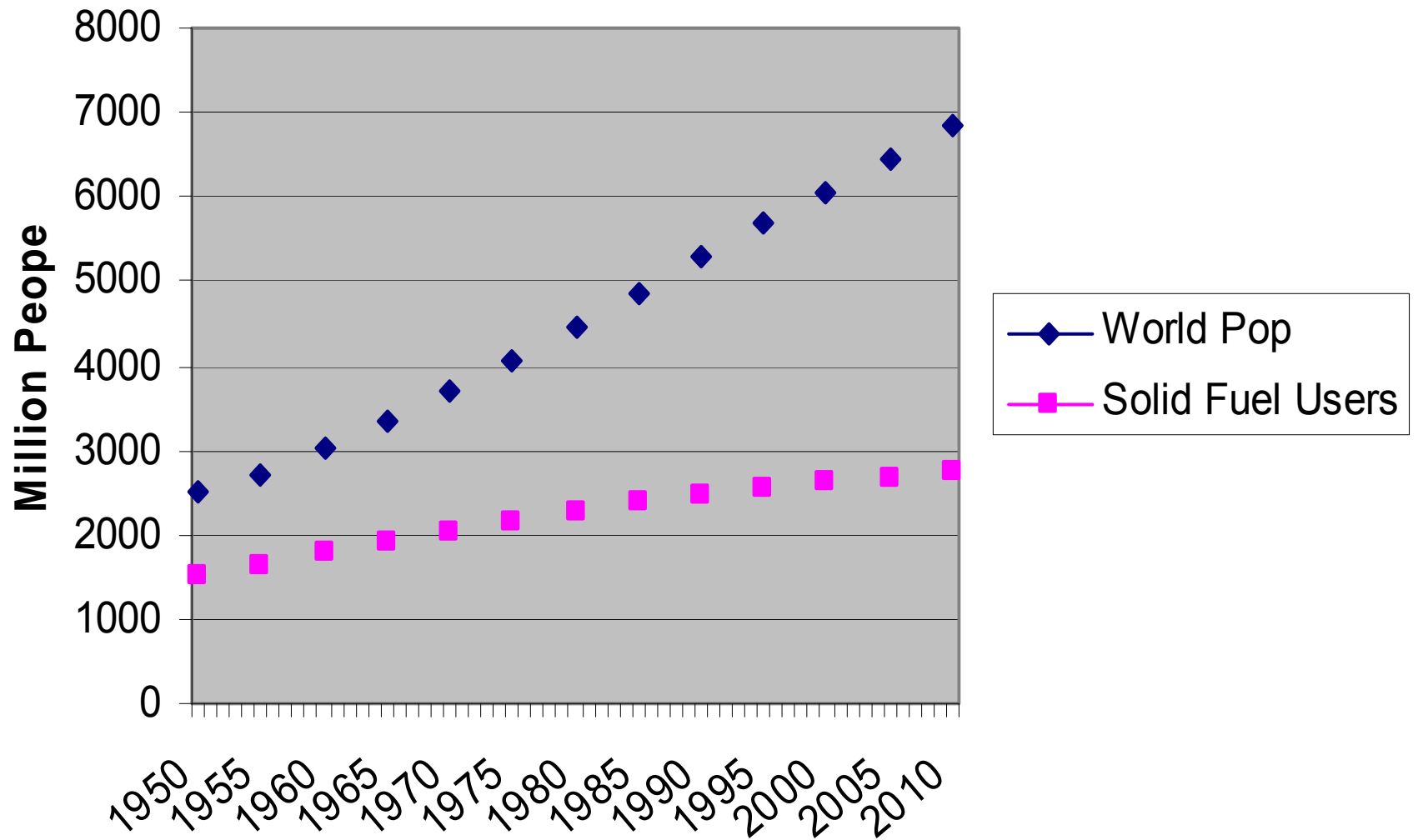


% of HH Exposed to HAP



**Comparative Risk  
Assessment (CRA)**  
2011- preliminary,  
Adair, et al.

# World Population Using Solid Fuels



The three major solid fuels



# Woodsmoke is natural – how can it hurt you?

Or, since wood is mainly just carbon, hydrogen, and oxygen, doesn't it just change to  $\text{CO}_2$  and  $\text{H}_2\text{O}$  when it is combined with oxygen (burned)?

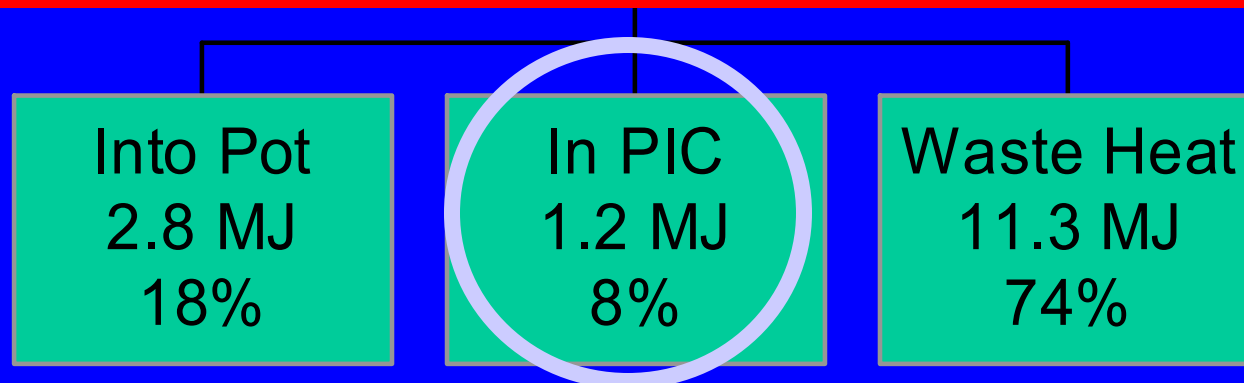


Reason: the combustion efficiency is far less than 100%

# Energy flows in a well-operating traditional wood-fired Indian cooking stove

A Toxic Waste Factory!!

Typical biomass cookstoves convert 6-20% of the fuel carbon to toxic substances



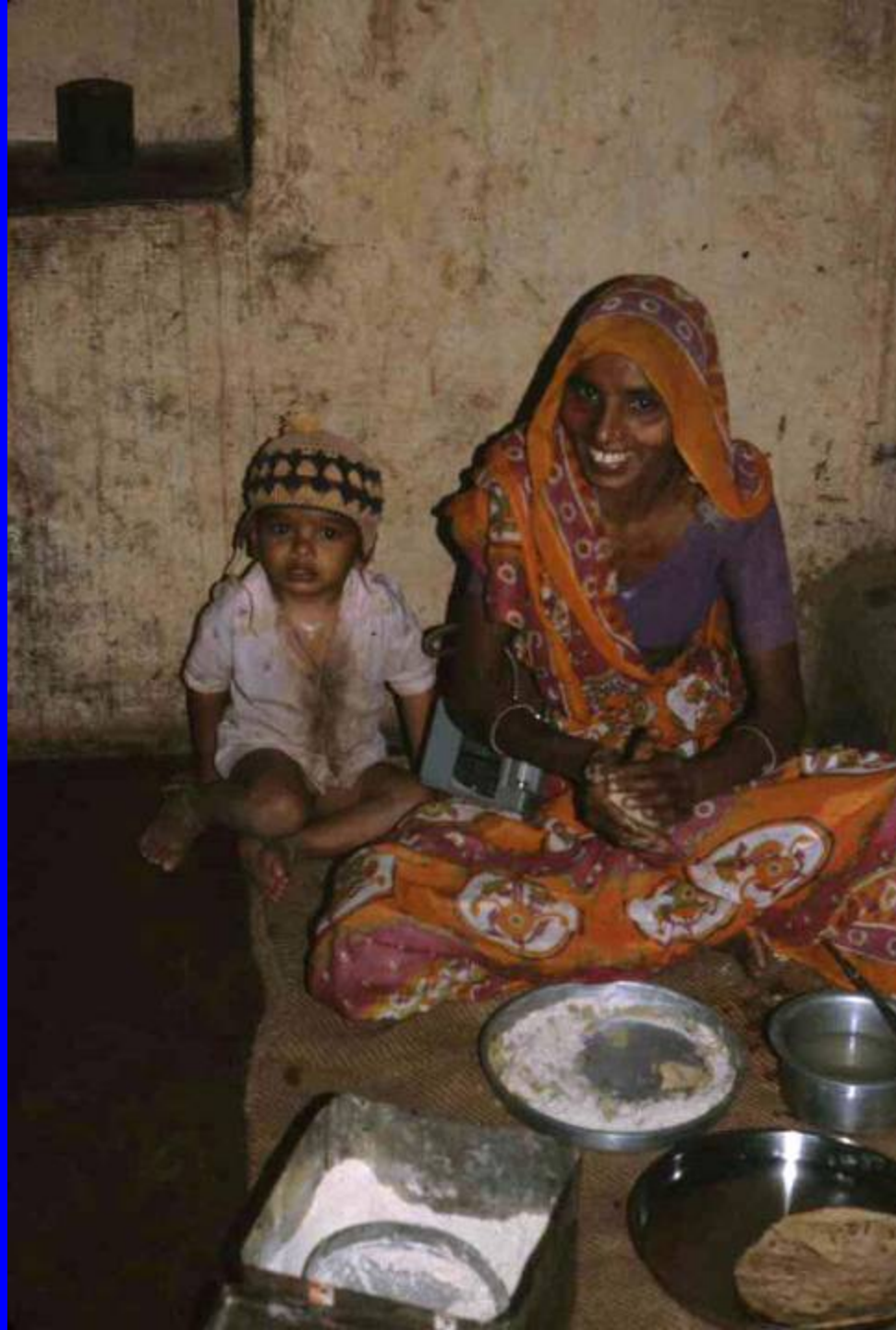
PIC = products of incomplete combustion = CO, HC, C, etc.

Source:  
Smith,  
et al.,  
2000

# Toxic Pollutants in Biomass Fuel Smoke from Simple (poor) Combustion

- Small particles, CO, NO<sub>2</sub>
- Hydrocarbons
  - 25+ saturated hydrocarbons such as *n-hexane*
  - 40+ unsaturated hydrocarbons such as *1,3 butadiene*
  - 28+ mono-aromatics such as *benzene & styrene*
  - 20+ polycyclic aromatics such as *benzo(α)pyrene*
- Oxygenated organics
  - 20+ aldehydes including *formaldehyde & acrolein*
  - 25+ alcohols and acids such as *methanol*
  - 33+ phenols such as *catechol & cresol*
  - Many quinones such as *hydroquinone*
  - Semi-quinone-type and other radicals
- Chlorinated organics such as *methylene chloride* and *dioxin*

Source: Naeher et al,  
*J Inhal Tox*, 2007



How much  
Ill-health?

ALRI/  
Pneumonia

Diseases for which we have  
epidemiological studies

COPD

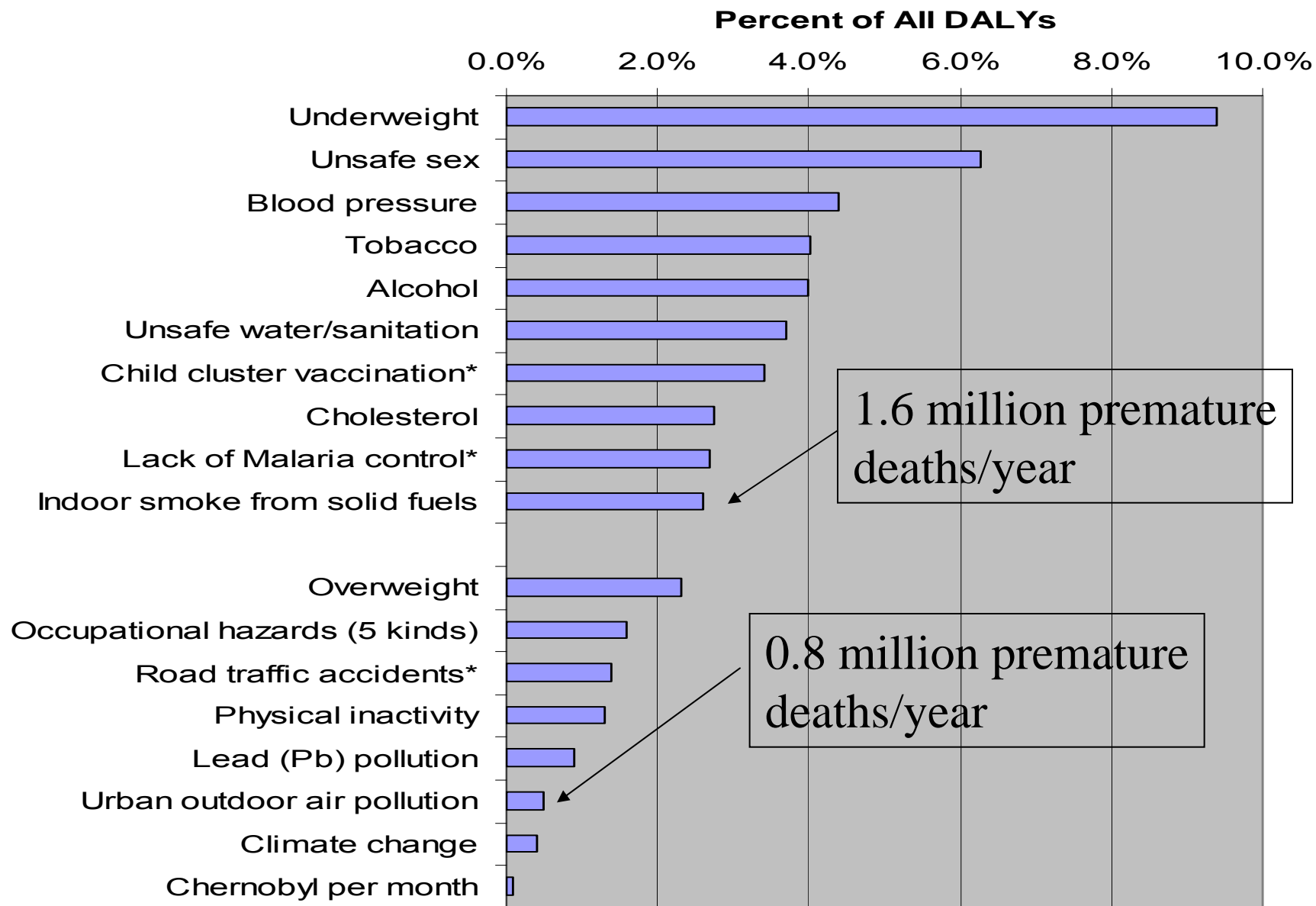
Lung cancer  
(coal)



These three diseases were included in the  
2004 Comparative Risk Assessment  
Managed and published by WHO

First ever comprehensive risk assessment  
with consistent rules of evidence  
and common databases

# Global Burden of Disease from Top 10 Risk Factors plus selected other risk factors



# Global Burden of Disease Database and Comparative Risk Assessment World Health Organization

Being completely updated  
For 2011 release

For household air pollution:  
New exposure assessment modeling  
New outcome estimates based on meta-analyses  
ALRI, COPD, Lung Cancer  
Low birth weight, cataracts, cardiovascular

ALRI/  
Pneumonia

Low birth  
weight

Stillbirth

Diseases for which we have  
epidemiological studies - 2011

COPD

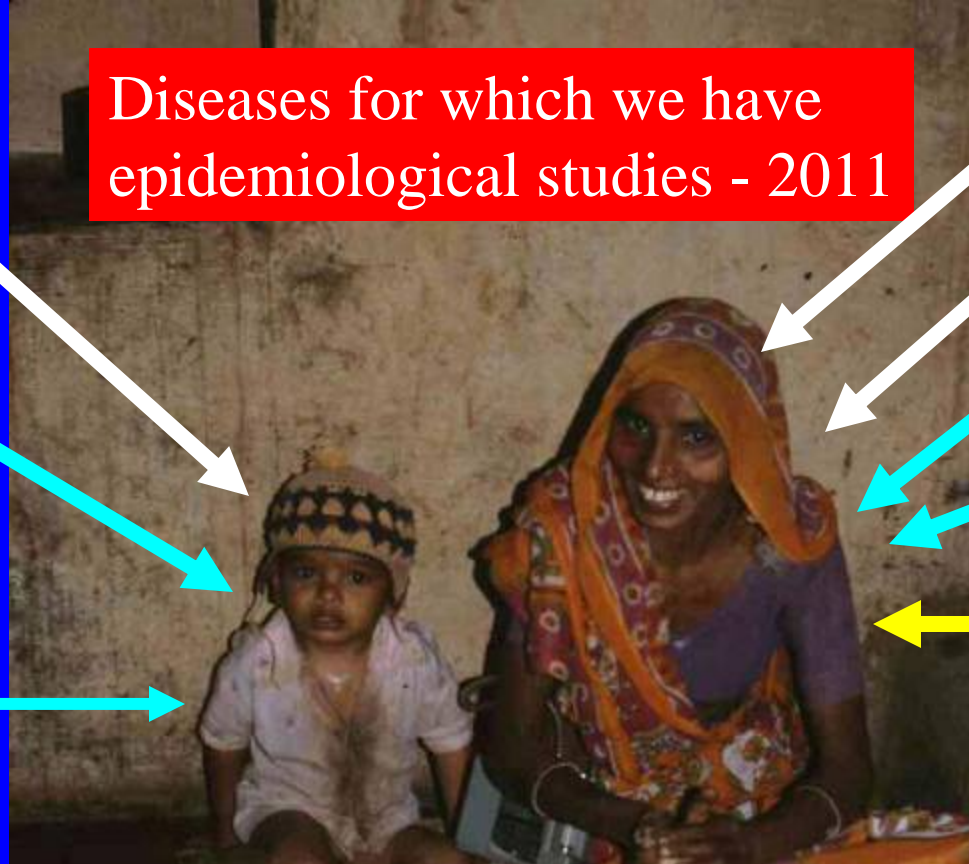
Lung cancer  
(coal)

Lung cancer  
(biomass)

Blindness  
(cataracts, opacity)

CV disease

Blood pressure  
ST-segment



These additional diseases will be included in the  
2011 Comparative Risk Assessment

In addition, using evidence from other  
exposure sources, CVD will be included

There is epi evidence for these other diseases, but  
considered insufficient to include in the  
2011 Comparative Risk Assessment



Cognitive  
Impairment

Birth defects

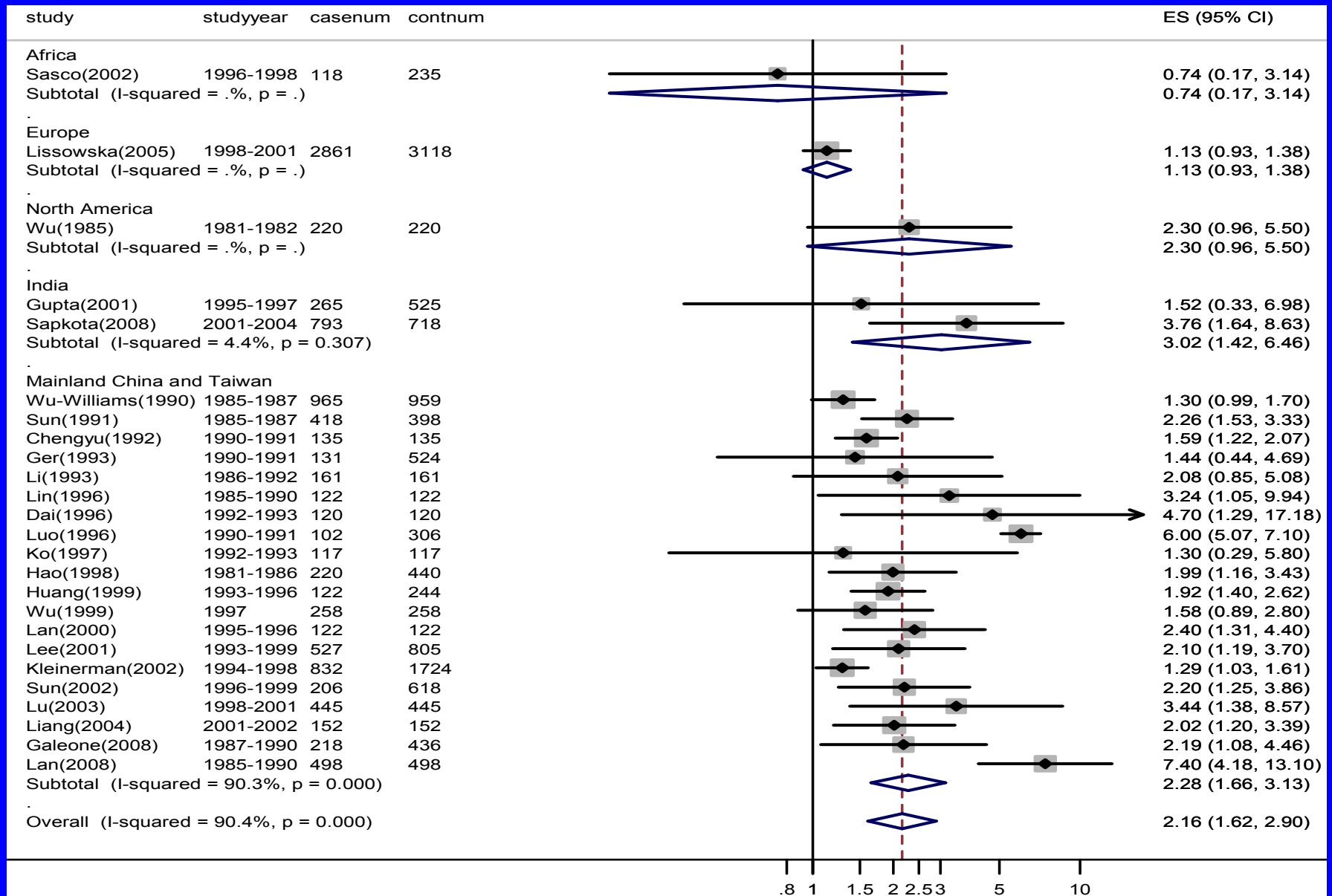
Asthma?

Burns and the health/safety  
impacts of fuel gathering

Tuberculosis  
ALRI

Other cancers  
(cervical, NP,  
upper airway)

# Summary risk estimates of lung cancer associated with in-home coal use for heating and cooking by geographic region



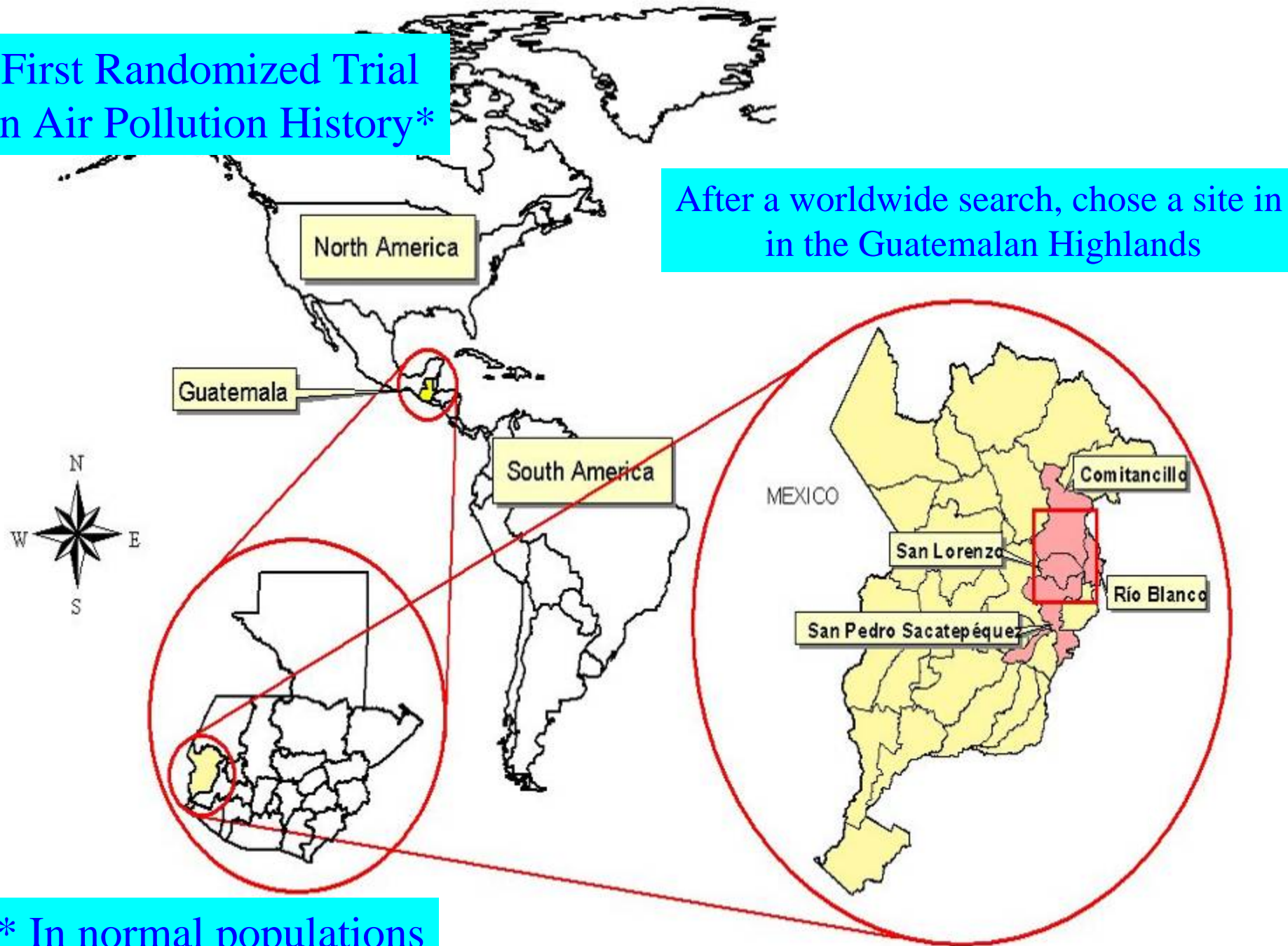
# Summary of recent results

- Pneumonia – 3.1 times
- Chronic Obstructive Lung Disease – 2.7x women; 1.9x men
- Lung cancer from coal use – 2.0x women; 1.4 men
- Cataracts – 2.4x women
- Heart disease – 2.0x

# Story of Two Conferences

- Air pollution conference
  - High exposures to large vulnerable population
  - No more health effects work needed
- International health conference
  - Still doubt about causality
  - Need to know exact benefit to be expected
- Where are your randomized controlled trials?

# First Randomized Trial In Air Pollution History\*



\* In normal populations

# RESPIRE – Randomized trial (n=518)

Impact on pneumonia up to 18 months of age



Traditional open 3-stone fire:  
kitchen 48-hour  $\text{PM}_{2.5}$  levels of  
600 - 1200  $\mu\text{g}/\text{m}^3$

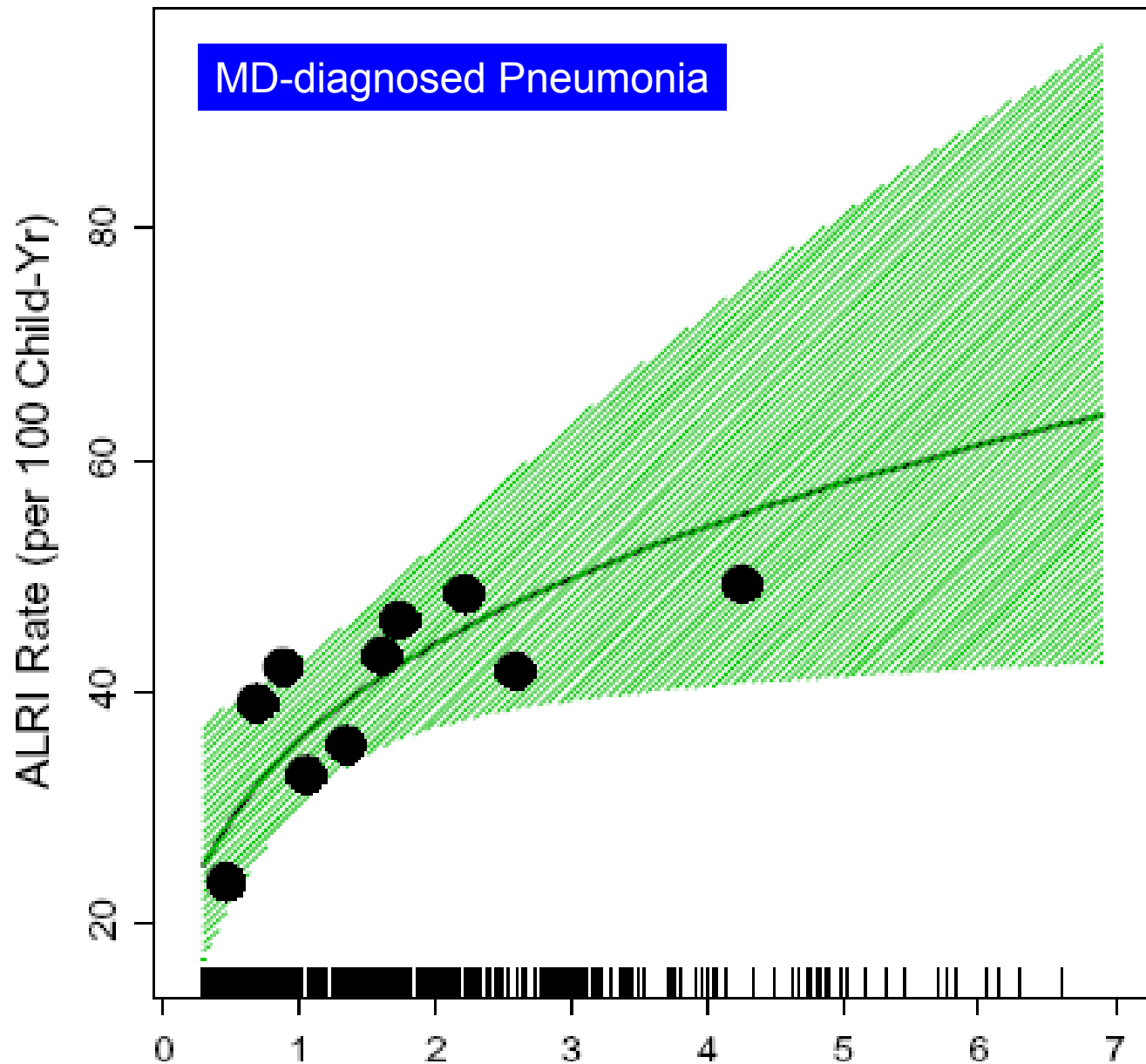


Chimney wood stove, locally made  
and popular with households

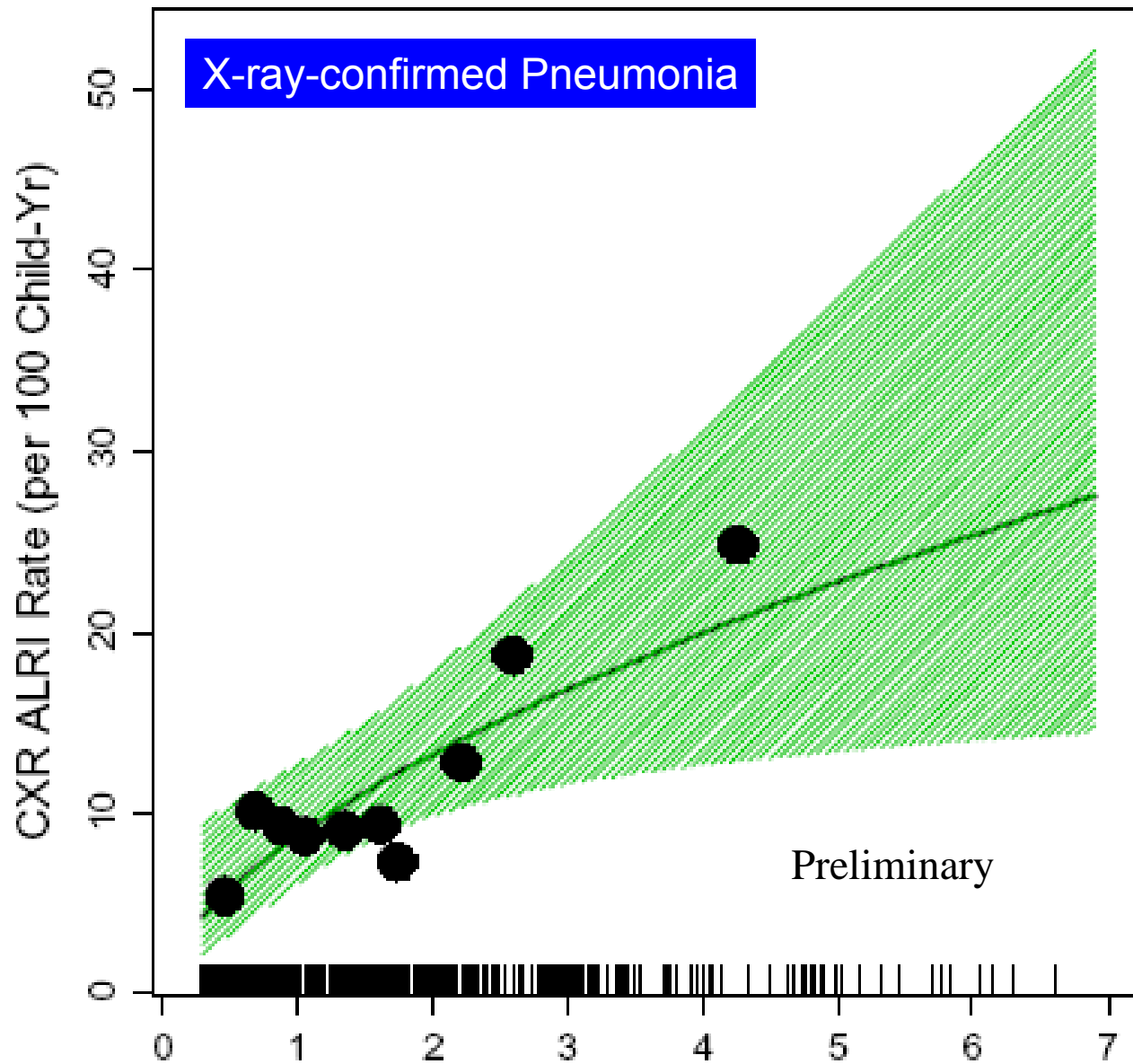


CO monitor

CO monitor



Approximate Mean PM2.5 exposure in 100s of ug/m3

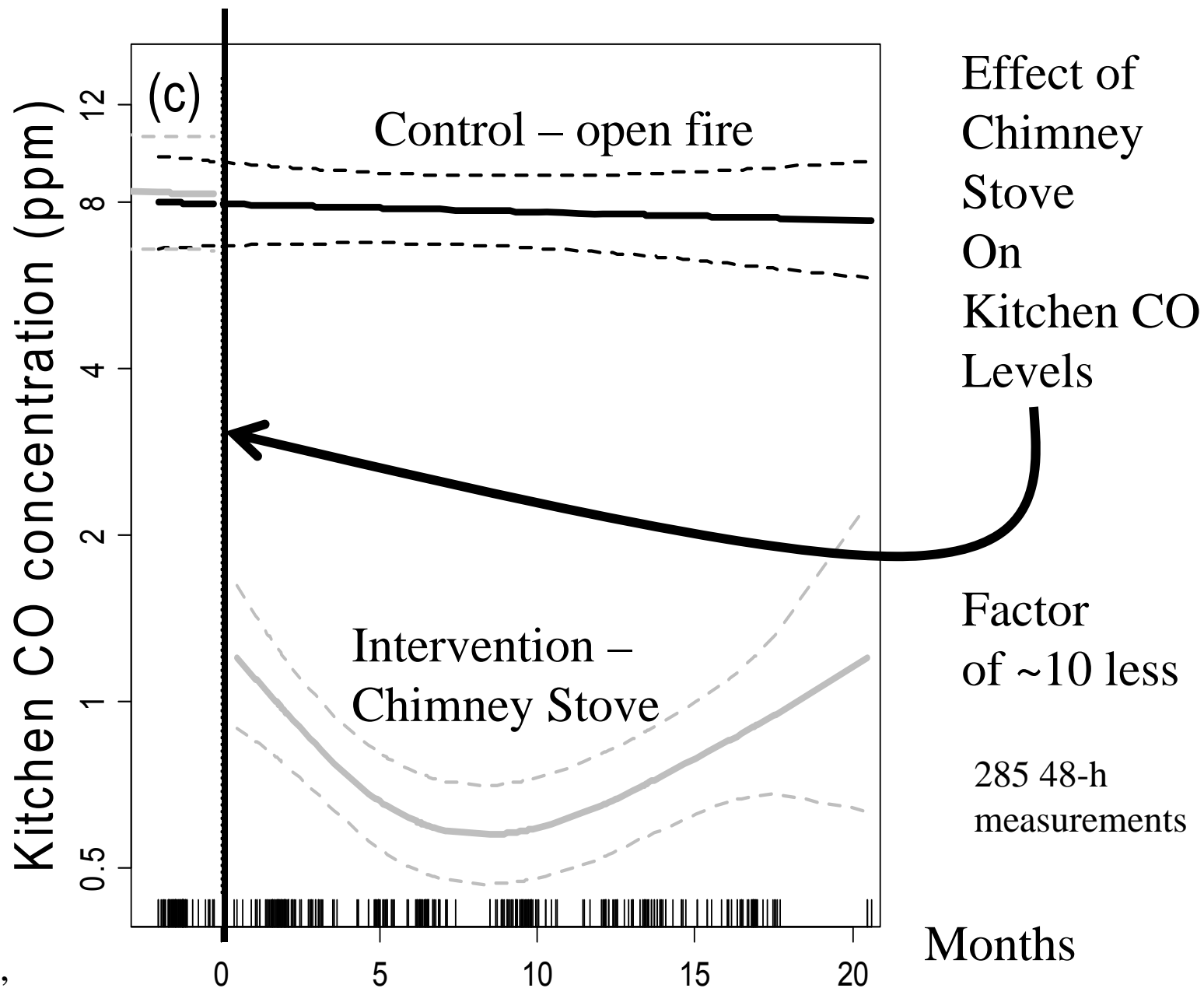


Approximate Mean PM2.5 exposure in 100s of  $\mu\text{g}/\text{m}^3$

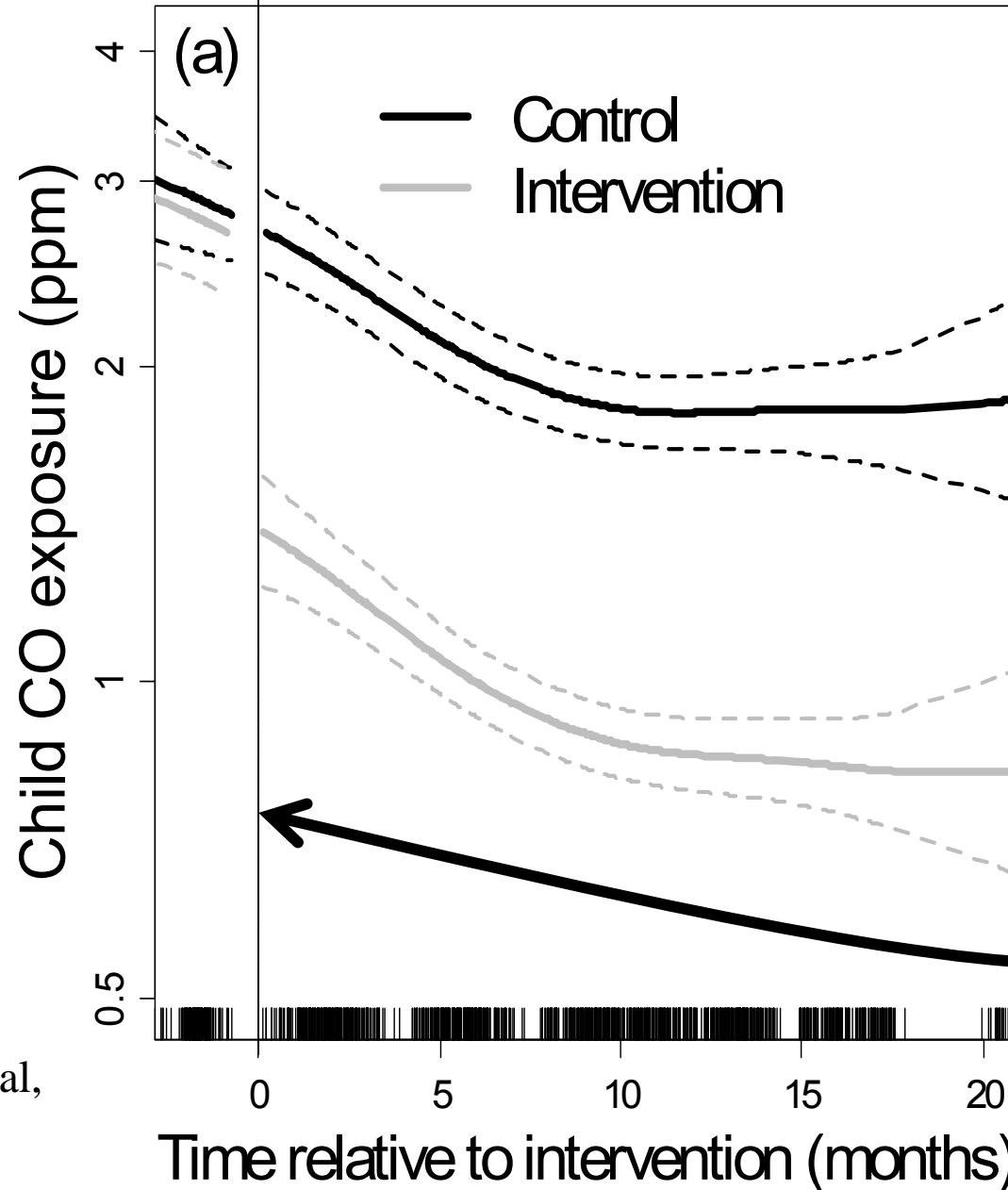
## RESPIRE: Pneumonia Reductions with Exposure Reduction Preliminary Results

Exposure reduction	Overall MD- pneumonia	Severe (hypoxic) MD-pneumonia	CXR pneumonia	Severe (hypoxic) CXR pneumonia
25%	0.92 (0.86, 0.99)	0.88 (0.80, 0.97)	0.84 (0.74, 0.96)	0.79 (0.69, 0.95)
50%	0.82 (0.70, 0.98)	0.73 (0.59, 0.92)	0.66 (0.49, 0.91)	0.56 (0.40, 0.88)
75%	0.67 (0.50, 0.96)	0.53 (0.35, 0.84)	0.44 (0.24, 0.83)	0.31 (0.16, 0.78)
90%	0.51 (0.31, 0.93)	0.35 (0.17, 0.76)	0.26 (0.09, 0.74)	0.15 (0.05, 0.67)

# Guatemala RCT: Kitchen Concentrations



# Infant Exposures



1888 48-h  
measurements

Effect of  
Chimney  
Stove  
On  
Infant  
Exposures  
- 2x less

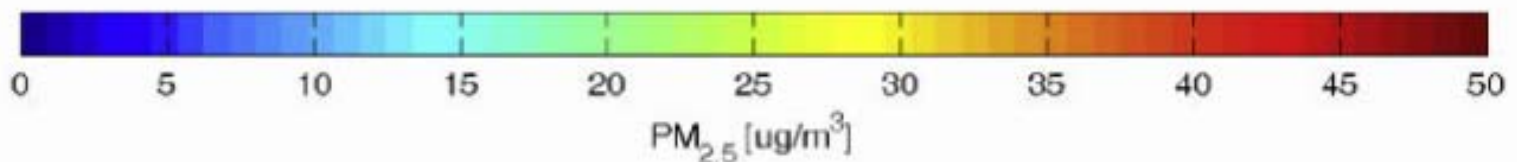
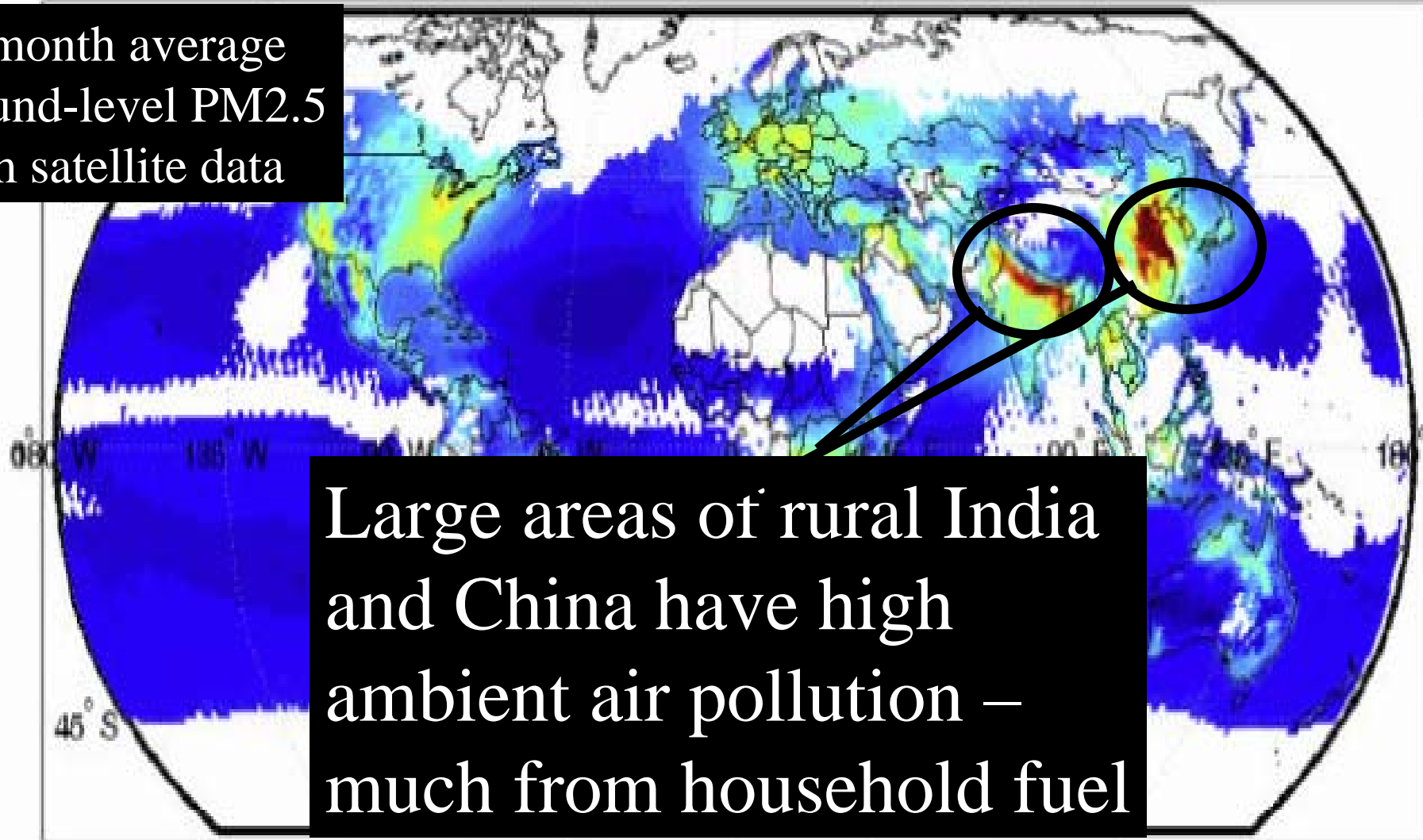
Kitchens down by 10x, but children exposure down by only 2x, because

- Time-activity: the kids do not spend their entire day in the kitchen
- Household (or “neighborhood”) pollution: a chimney does not reduce smoke, but just shifts it outside into the household environment, where the difference between intervention and control households was less
- No significant difference in bedrooms



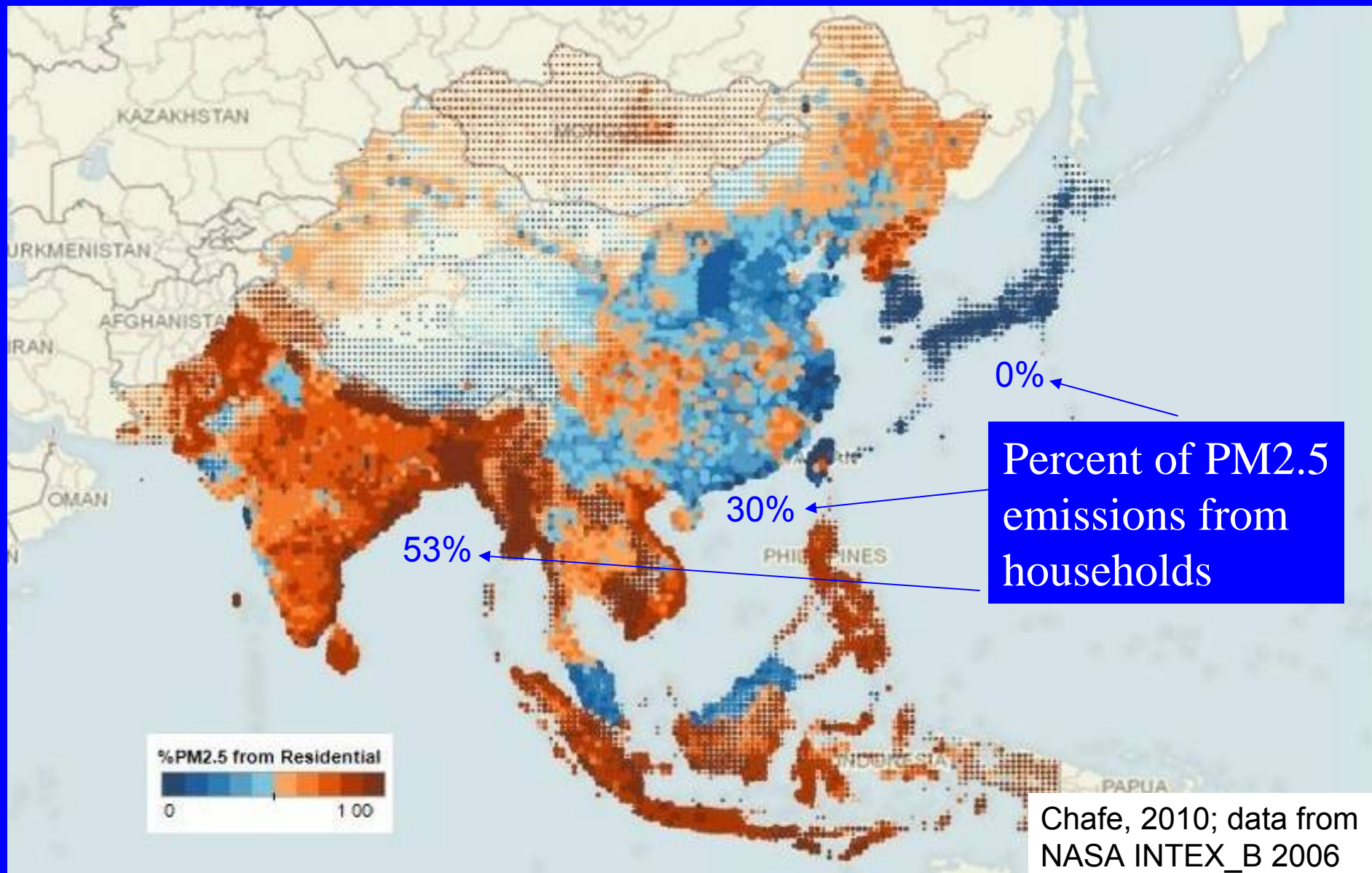
20-month average  
ground-level PM<sub>2.5</sub>  
from satellite data

MODIS



# NASA INTEX\_B Database

## Percent PM<sub>2.5</sub> emissions from households



# Heart Disease and Combustion Particle Doses

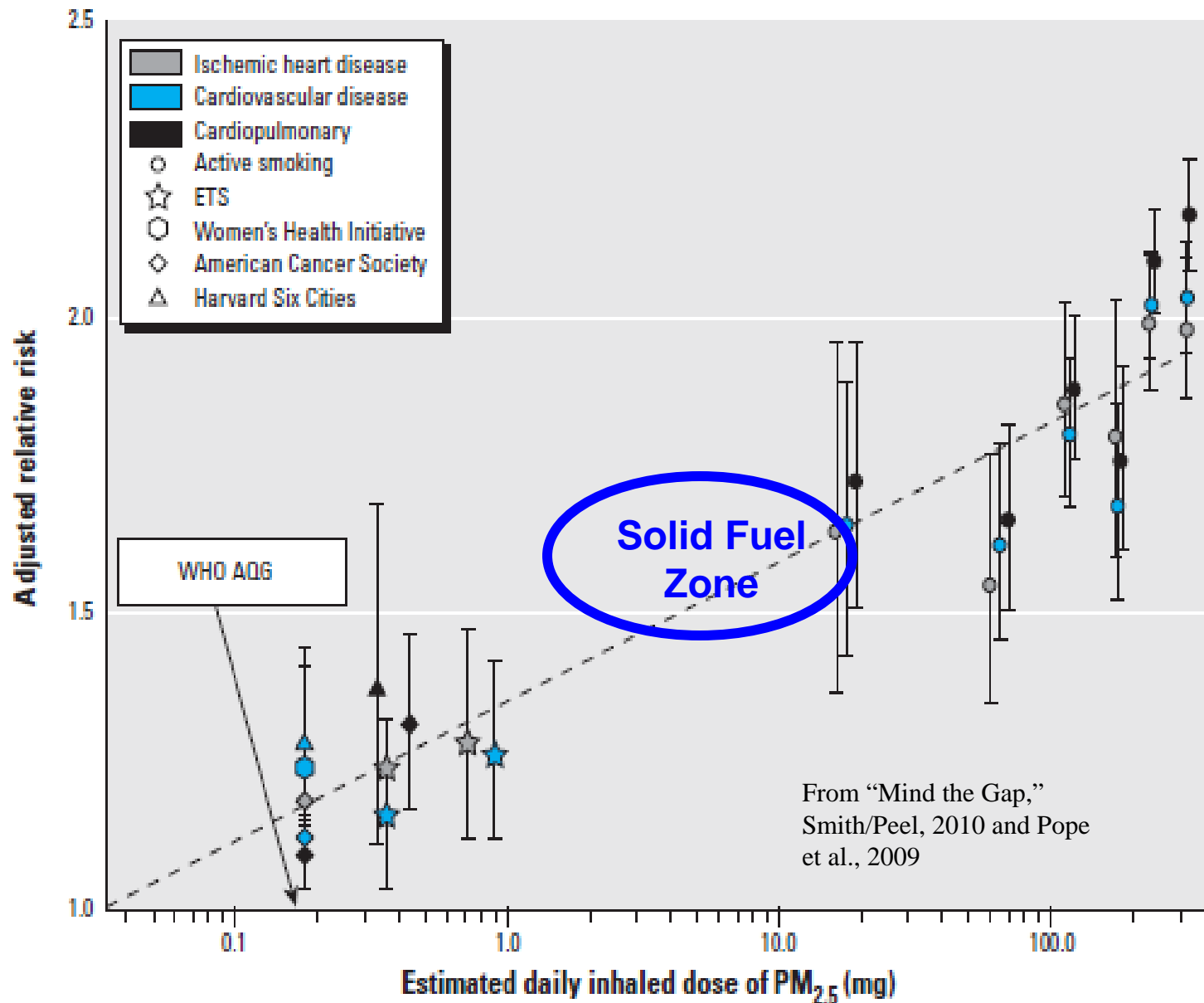
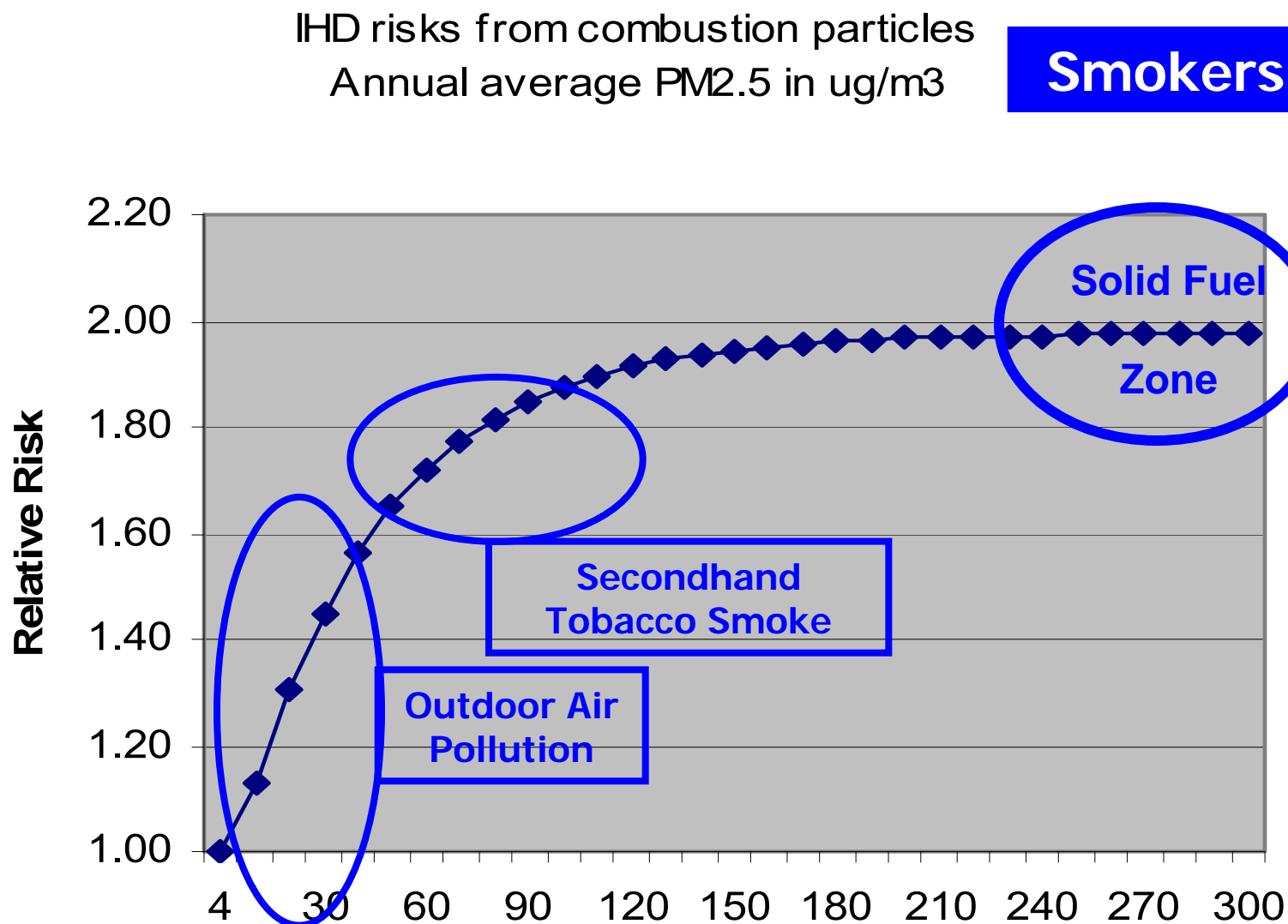


Table 2. Adjusted relative risk estimates<sup>a</sup> for various increments of exposure from cigarette smoking (versus never smokers), second hand cigarette smoke, and ambient air pollution from the present analysis and selected comparison studies.

Source of risk estimate	Increments of Exposure	Adjusted RR (95% CI)				Estimated Daily Dose PM <sub>2.5</sub> (mg) <sup>b</sup>
		Lung Cancer	IHD	CVD	CPD	
ACS- present analysis	≤3 (1.5) cigs/day	10.44 (7.30-14.94)	1.61 (1.27-2.03)	1.58 (1.32-1.89)	1.72 (1.46-2.03)	18
ACS- present analysis	4-7 (5.5) cigs/day	8.03 (5.89-10.96)	1.64 (1.37-1.96)	1.73 (1.51-1.97)	1.84 (1.63-2.08)	66
ACS- present analysis	8-12 (10) cigs/day	11.63 (9.51-14.24)	2.07 (1.84-2.31)	2.01 (1.84-2.19)	2.10 (1.94-2.28)	120
ACS- present analysis	13-17 (15) cigs/day	13.93 (11.04-17.58)	2.18 (1.89-2.52)	1.99 (1.77-2.23)	2.08 (1.87-2.32)	180
ACS- present analysis	18-22 (20) cigs/day	19.88 (17.14-23.06)	2.36 (2.19-2.55)	2.42 (2.28-2.56)	2.52 (2.39-2.66)	240
ACS- present analysis	23-27 (25) cigs/day	23.82 (18.80-30.18)	2.29 (1.91-2.75)	2.33 (2.02-2.69)	2.33 (2.03-2.67)	300
ACS- present analysis	28-32 (30) cigs/day	26.82 (22.54-31.91)	2.22 (1.97-2.49)	2.17 (1.98-2.38)	2.39 (2.19-2.60)	360
ACS- present analysis	33-37 (35) cigs/day	26.72 (18.58-38.44)	2.58 (1.91-3.47)	2.52 (1.98-3.19)	2.83 (2.28-3.52)	420
ACS- present analysis	38-42 (40) cigs/day	30.63 (25.79-36.38)	2.30 (2.05-2.59)	2.37 (2.16-2.59)	2.61 (2.40-2.84)	480
ACS- present analysis	43+ (45) cigs/day	39.16 (31.13-49.26)	2.00 (1.62-2.48)	2.17 (1.84-2.56)	2.37 (2.04-2.76)	540
ACS-air pol. original	24.5 µg/m <sup>3</sup> ambient PM <sub>2.5</sub>	-----	-----	-----	1.31(1.17-1.46)	0.44
ACS-air pol. extend.	10 µg/m <sup>3</sup> ambient PM <sub>2.5</sub>	1.14(1.04-1.23)	1.18(1.14-1.23)	1.12(1.08-1.15)	1.09(1.03-1.16)	0.18
HSC-air pol. original	18.6 µg/m <sup>3</sup> ambient PM <sub>2.5</sub>	-----	-----	-----	1.37(1.11-1.68)	0.33
HSC-air pol. extend.	10 µg/m <sup>3</sup> ambient PM <sub>2.5</sub>	1.21(0.92-1.69)	-----	1.28(1.13-1.44)	-----	0.18
WHI-air pol.	10 µg/m <sup>3</sup> ambient PM <sub>2.5</sub>	-----	-----	1.24(1.09-1.41) <sup>c</sup>	-----	0.18
SGR-SHS	Low- moderate SHS exp.	-----	-----	1.16(1.03-1.32)	-----	0.36
SGR-SHS	Moderate-high SHS exp	-----	-----	1.26(1.12-1.42)	-----	0.90
SGR-SHS	Live with smoking spouse	1.21(1.13-1.30)	-----	-----	-----	0.54
SGR-SHS	Work with SHS exposure	1.22(1.13-1.33)	-----	-----	-----	0.72
INTERHEART	1-7 hrs/wk SHS exp.	-----	1.24(1.17-1.32) <sup>d</sup>	-----	-----	0.36
INTERHEART	Live with smoking spouse	-----	1.28(1.12-1.47) <sup>d</sup>	-----	-----	0.54

Pope et al.  
Environmental Health  
Perspectives  
 2011, in press

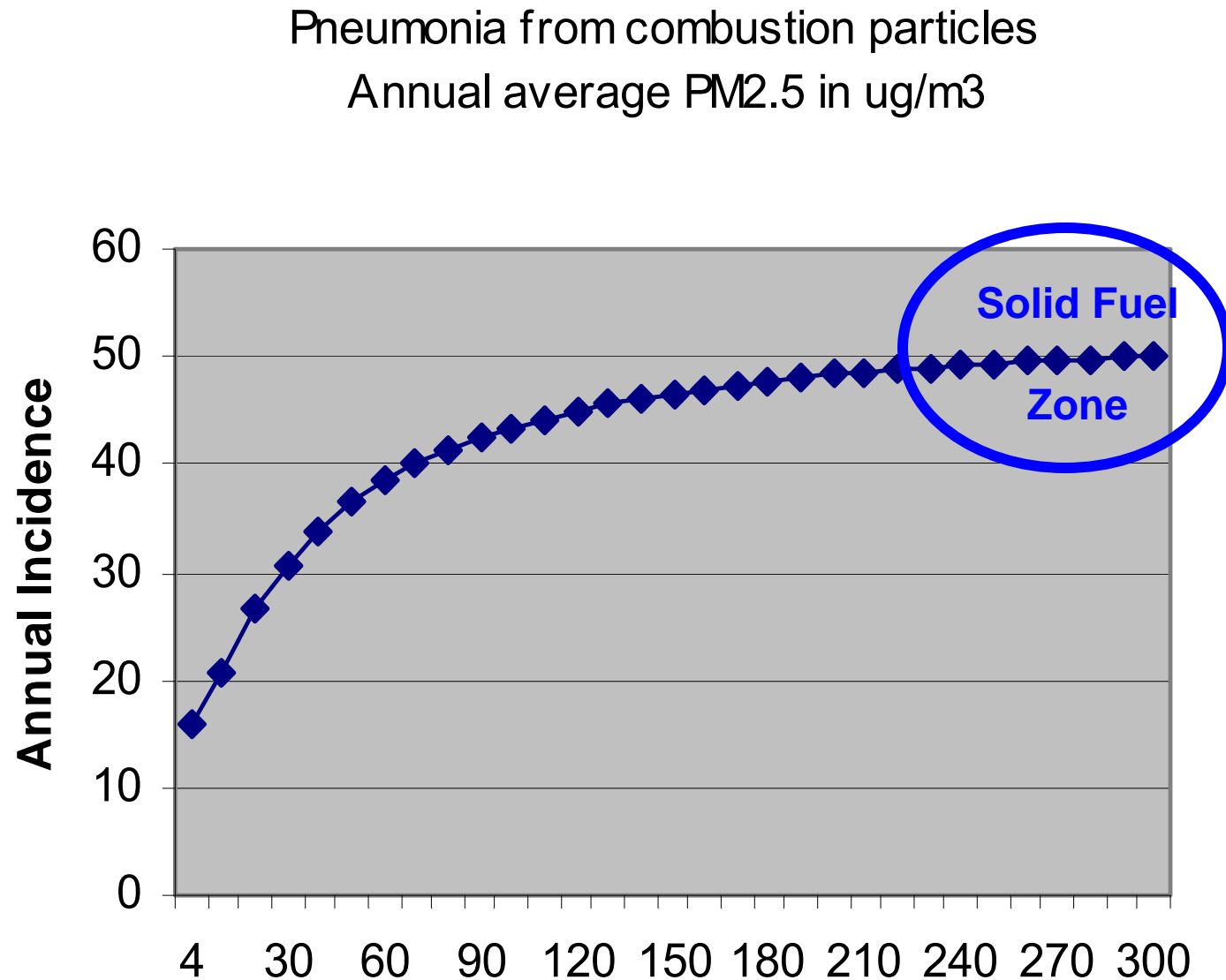
# Generalized Exposure-Response: Outdoor Air, SHS, and Smoking



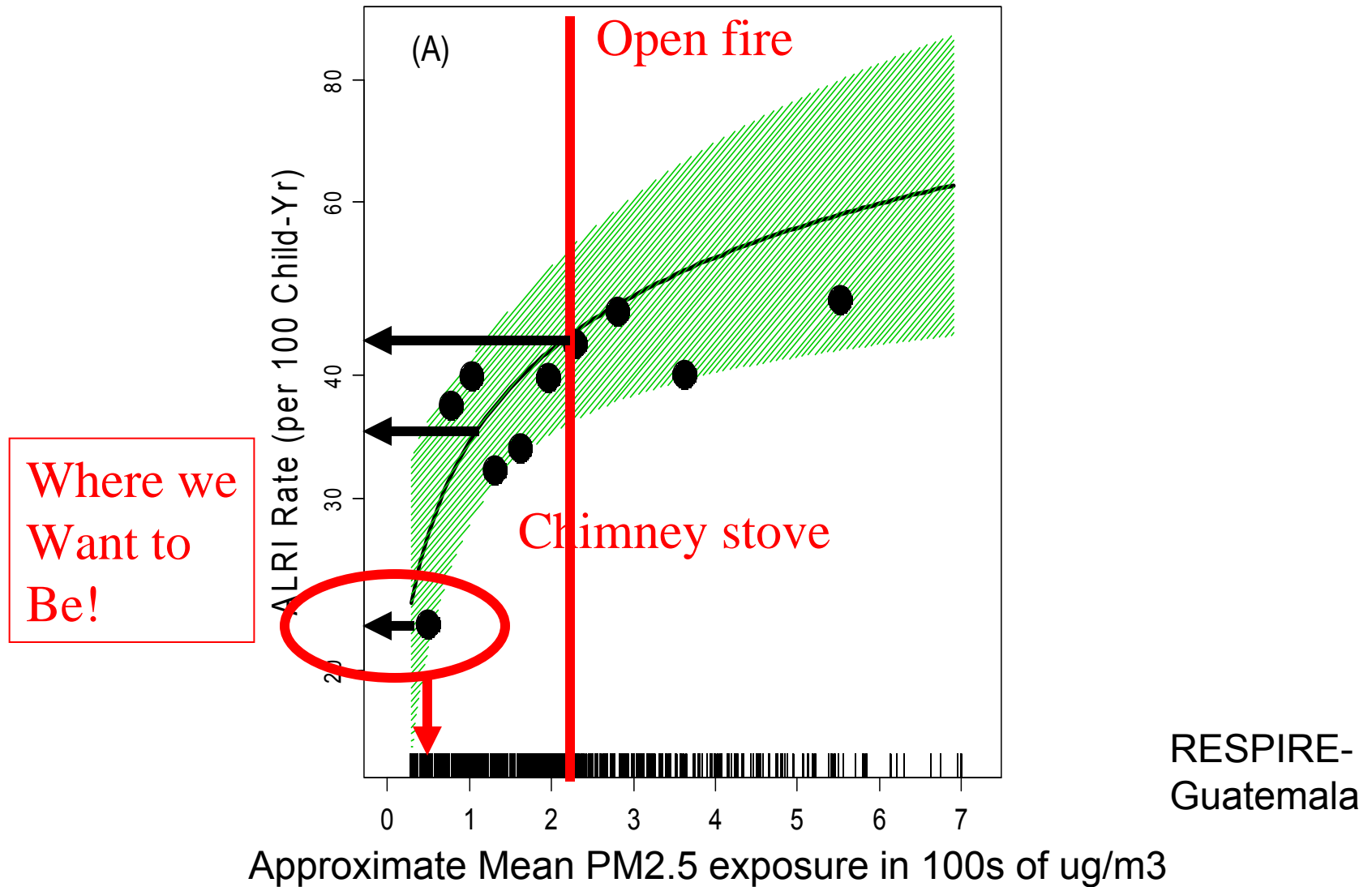
**Smokers** →

CRA,  
2011

# Generalized Exposure-Response: Outdoor Air, SHS, and HAP



# MD-diagnosed Acute Lower Respiratory Infection





# SMALL, SMART, FAST, & CHEAP

monitoring devices for household energy & health

Ajay Pillarisetti, Ilse Ruiz-Mercado, and Nick Lam on behalf of Prof. Kirk R. Smith's Research Group at University of California, Berkeley  
Visit [obs.sph.berkeley.edu/krsmith](http://obs.sph.berkeley.edu/krsmith) for more information



## STOVE USE MONITORS UTILIZATION

Time-of-use measuring devices allow more accurate estimations and objective definitions of usage patterns including cooking periods, meal times, and technology adoption rates.

Stove Use Monitors (SUMS) quantify utilization of cookstoves to improve estimates of personal exposure and environmental benefits related to household energy use. SUMS are based on commercially available, low-cost, small temperature loggers.



The stainless steel temperature sensors are the size of a coin and can record time, date, and temperature. Programming and downloading data can be easily performed in the field. They are easy to use, unobtrusive, waterproof and tamper-resistant. They come with algorithms and software to systematically assess stove use patterns.

Measurements of stove surface temperature can be used to test the effectiveness of behavioral interventions on stove use. Because they give precise, unbiased measures of a simple physical parameter, statistically reliable information is provided using smaller sample sizes than required for a household survey.

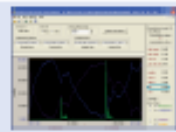
## PARTICLE AND TEMP SENSOR CONCENTRATION

The ability to measure concentrations of small airborne particles is vital in understanding adverse health effects from combustion-derived air pollution. Available instrumentation to conduct such measurements is complex and expensive. Such devices are appropriate for developed countries and ambient air monitoring stations. However, their routine use in real-world household environments is expensive & cumbersome. Monitoring locations may also be remote, where security is questionable and electrical power not available, limiting the applicability of conventional instruments. In an effort to fulfill the needs for small, smart, fast, and cheap particle monitors that could be deployed easily in remote settings, a commercial smoke detector that uses optical scattering was identified and modified so that real-time signals could be logged continuously. This modified particle and temperature sensor is dubbed the UCB-PATS. Customized software handles data importing, graphing, and manipulation.

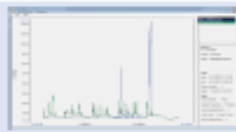


## Device Software & Sample Output

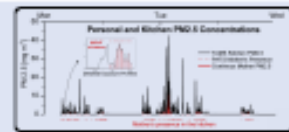
Each device is controlled by software allowing equipment launch, data download and manipulation, and reporting of data files for further analysis. Devices connect with the software over a serial port or via an USB to Serial converter.



Monitoring and processing downloaded data in the UCB-PATS data browser.



Stratified time of activity in Room 1003 - 1004, 1005, 1006, 1007 and 1008. Legend: High Accuracy and Low Accuracy are now available from UCB-PATS.



Continuous personal and kitchen PM<sub>2.5</sub> concentrations and activity patterns in a home setting on open fire stove.

## TIME-ACTIVITY MONITORING LOCATION

Measurement of exposure to pollutants is vital to the field of environmental health. The significance of a hazard depends on the amount of time a person is in contact with it. For instance, high indoor air pollution levels have been found in many homes globally. The risk of respiratory disease depends on the amount of time people spend in the presence of this pollution.

Time-Activity Monitoring System (TAMS) detects the presence or absence of individuals in an enclosed space. The system consists of one to five small ultrasound emitting devices worn on an individual's clothing. Each produces a distinct pattern that is emitted every few seconds. An ultrasound receiver is mounted on the wall of a room and detects the unique pattern from the device worn by an individual.

If the identifying signal pattern emitted from a particular locator is received a certain number of times during a minute, that locator, and presumably the person wearing it, is recorded as being present in the room. Field trials show good results, with a 93% accuracy rate as measured against direct observation.

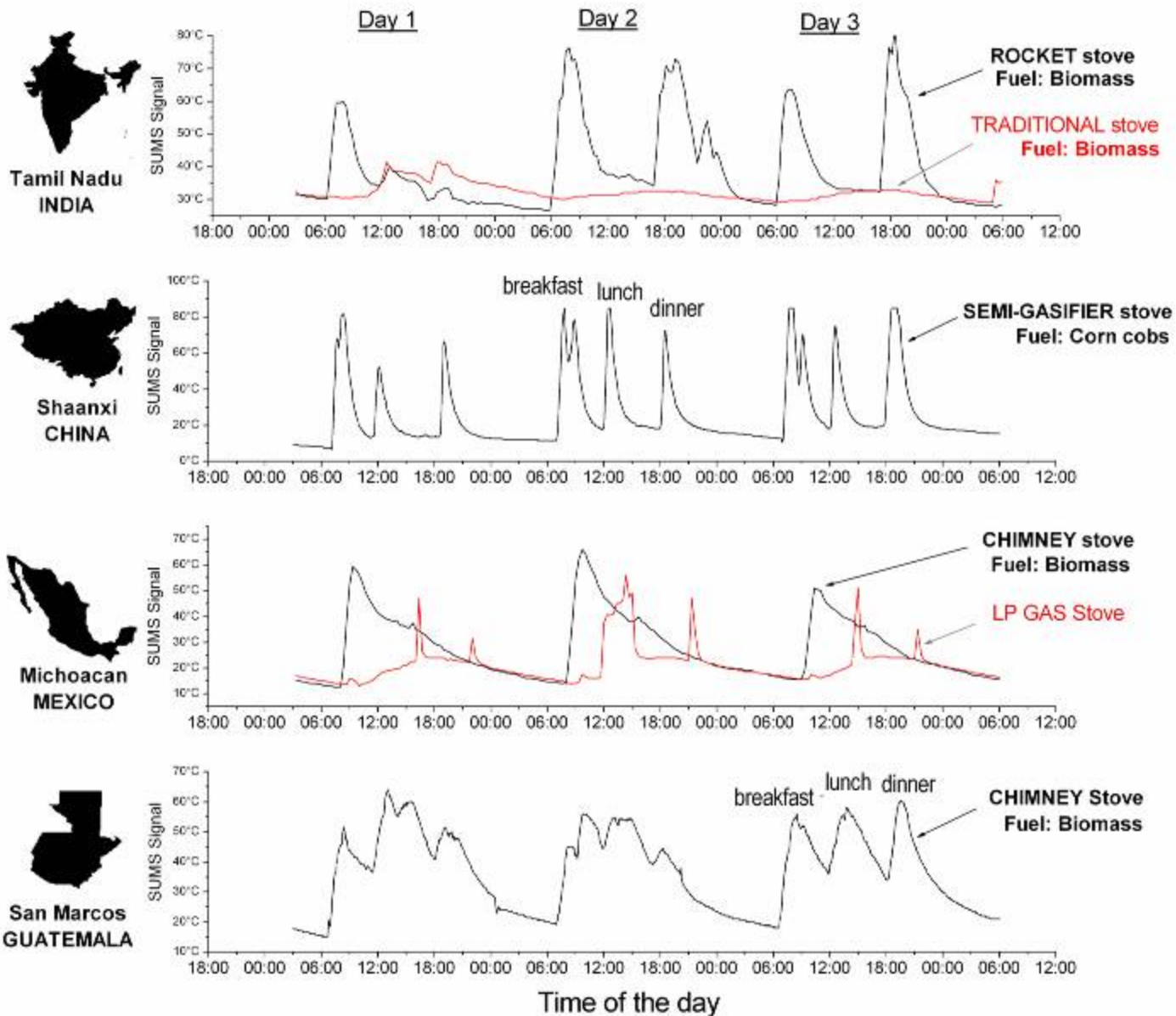


For more information, google "Kirk R Smith" • To acquire devices, visit [berkeleyair.com](http://berkeleyair.com)

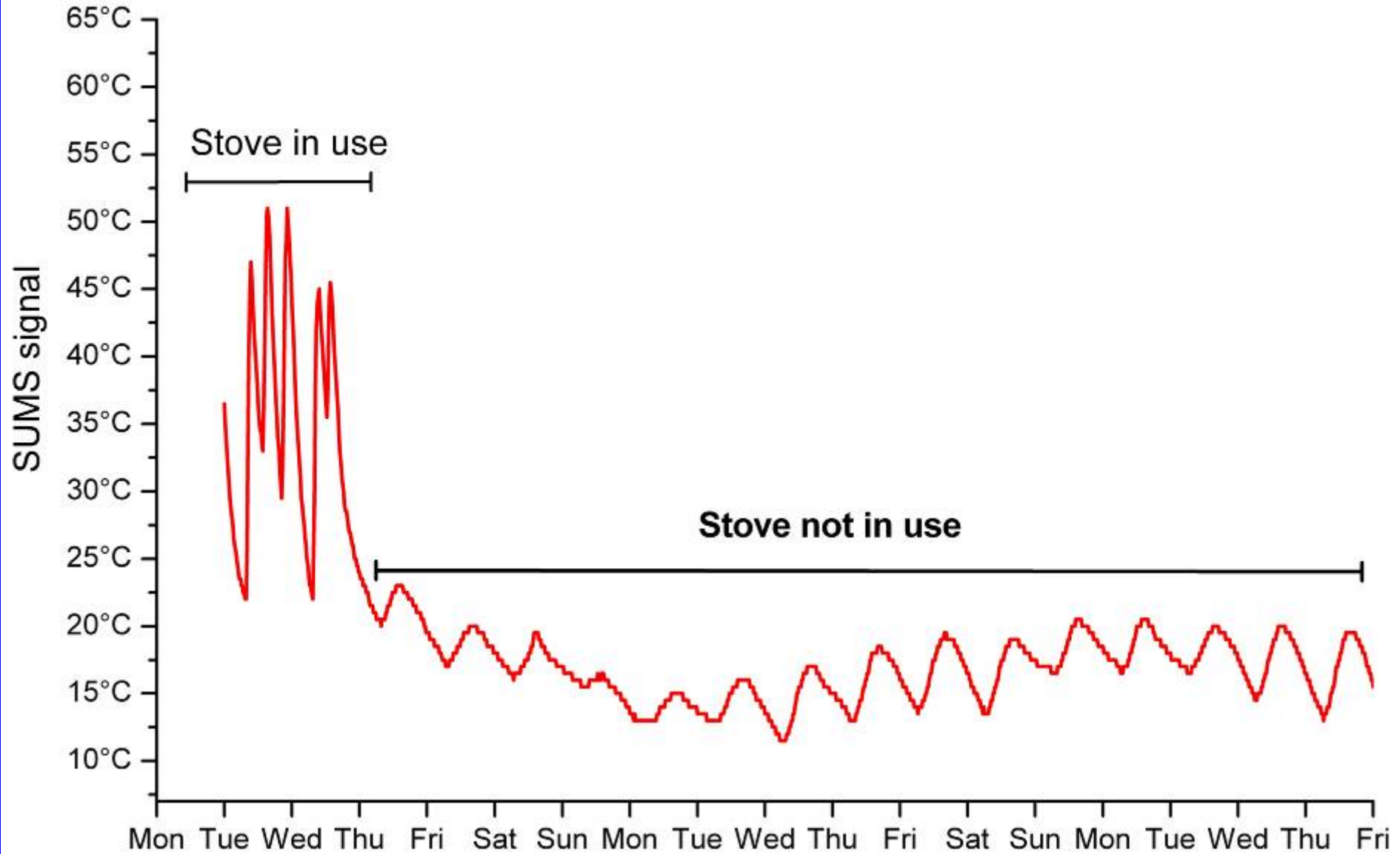
# The Stove Use Monitoring System: UCB-SUMS



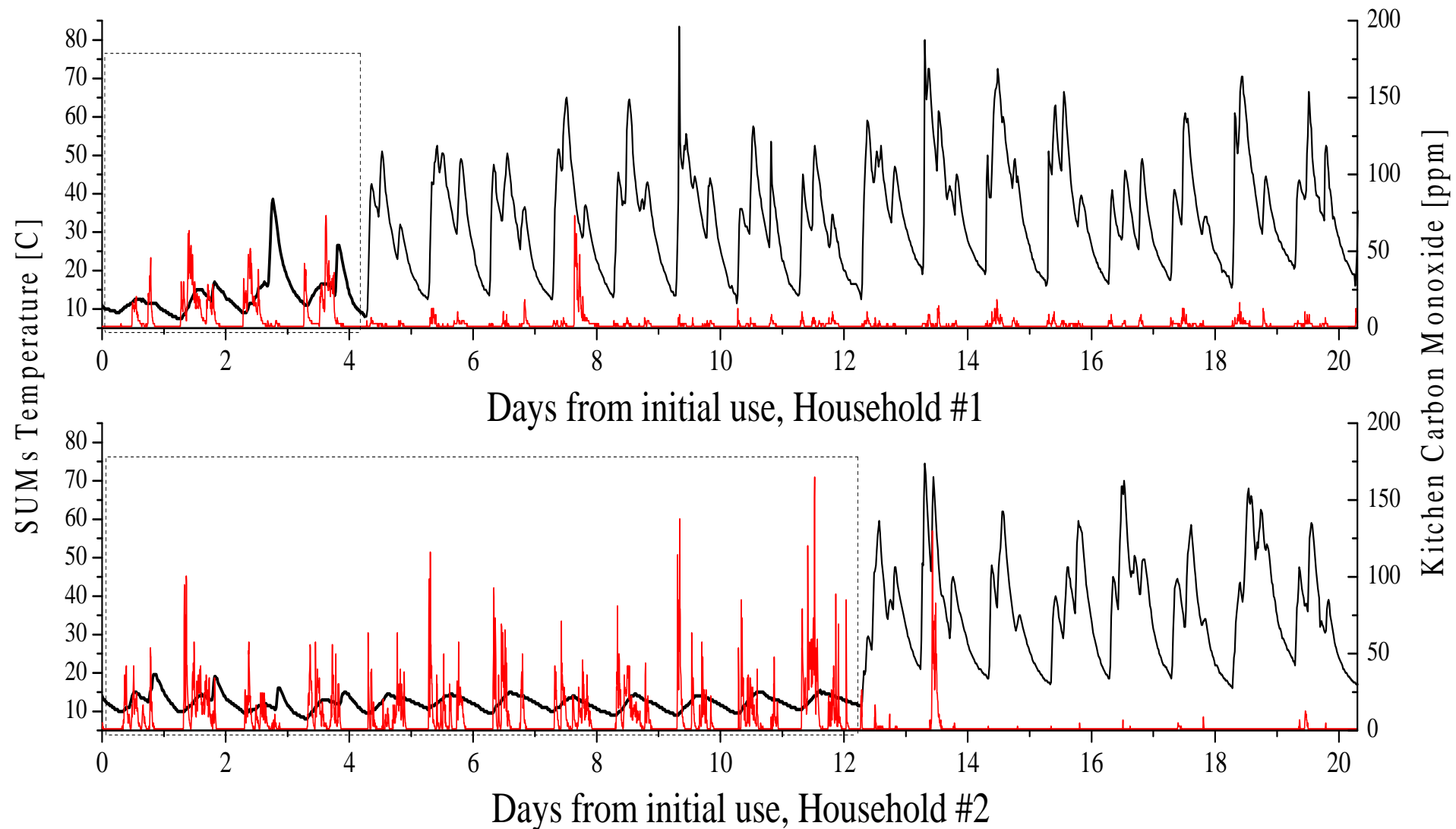
# Patterns of Stove Use from Around the World Captured with the UCB-SUMS

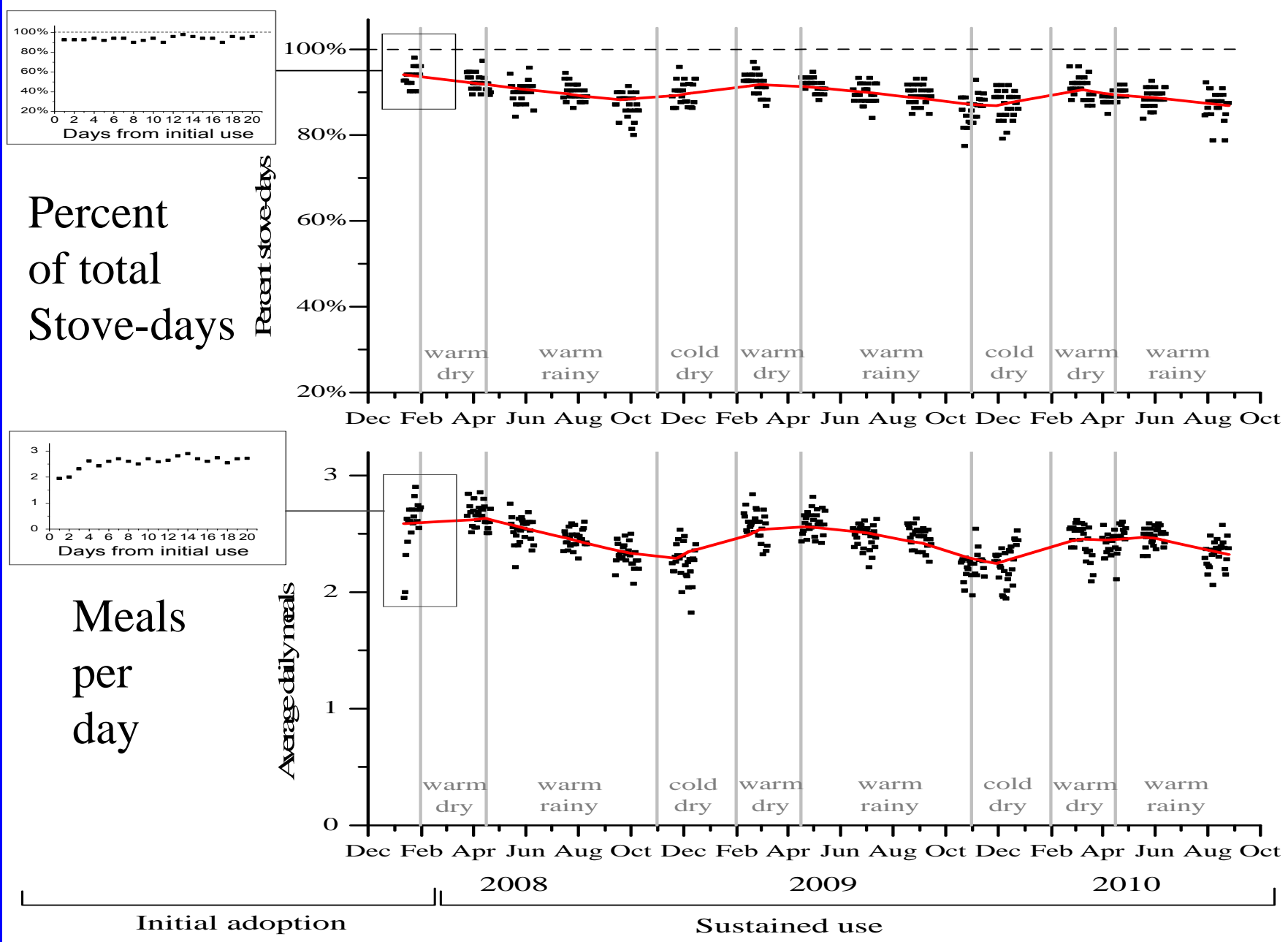


# Objective Monitoring with the UCB-SUMS System



# Stove Use Monitors (SUMs) in Action





# Principles by Which to Move Forward

- “Get rid of incomplete combustion” – bad for health, climate, ecosystems, agriculture and resource efficiency
- Chimneys are not enough – just spread the pollution around
- Much less value of a clean efficient heating stove if the house is poorly insulated and leaky
- “You don’t get what you expect, but what you inspect” -- need to monitor in the field for both technical performance and usage

# Stoves, a few principles.

- “Improved” has not meant clean. Need to combust cleanly, not just have good fuel efficiency or a chimney, although these are valuable as well
  - Truly clean stove/fuel systems are very few in number today, and field experience even more scarce
  - All truly clean (“advanced”) stoves use blowers, but with TEG technology, there is no constraint imposed by lack of electrical supply
- “The poor cannot afford to pay” --need to realign financing so that everyone pays, since all benefit – households, nations, globe
  - Poor will only pay for fuel savings, but many do not buy fuel and thus have little incentive
  - Cost of stoves that merely save fuel are much lower than those that are also clean -- thus sales alone will not bring large health/climate benefits

# The Mongolia of Not So Long Ago





This is half of  
Mongolia  
today

# Air Pollution Box Model

- Volume in m<sup>3</sup>
- Air Exchange Rate in (hour)<sup>-1</sup>
- Emissions in g/hour
- Concentration =  $C = E / (AER * V) =$
- $C = (g/hour) / ((\#/hour) * m^3) = g/m^3$

# Typical Village Cooking Situation

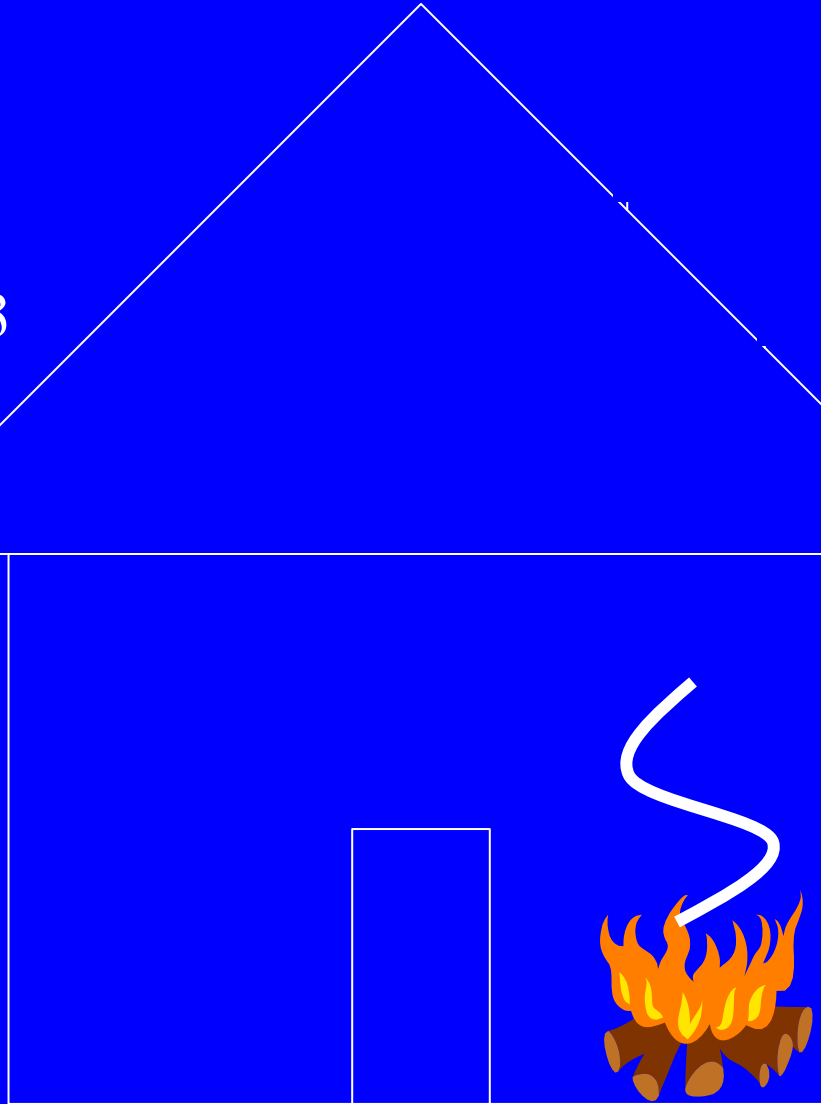
Volume ~ 40 m<sup>3</sup>

Wood use ~  
2 kg/h

Air Exchange  
Rate ~ 10

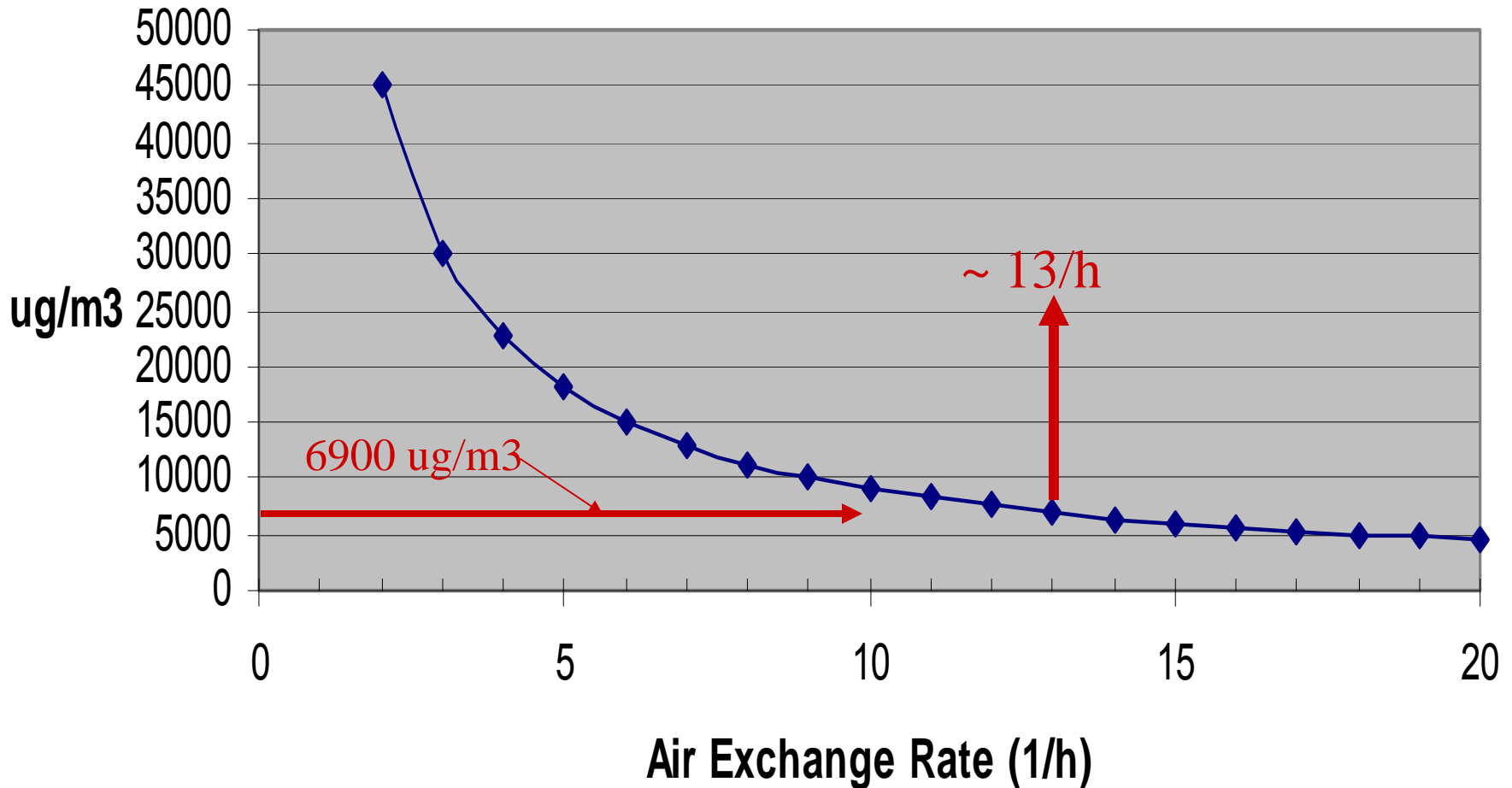
PM emission  
factor ~ 2 g/kg

↓  
PM emission  
Rate ~ 4 g/h



\*

## Apparent Air Exchange Rate in Village Hut



Vol = 42 m<sup>3</sup>; Fuel burn rate = 1.9 kg/h, during cooking

# Ulaanbaatar Room Model

- **Valley Volume** (4\*8\*0.3 km) ~**10 km<sup>3</sup>**
- **Air Exchange Rate** in (day)<sup>-1</sup> **at 1 m/sec wind** ~ **9 air changes per day**
- Heating fuel use for 130,000 households burning wood and coal – 1 million tons
- Average emission factor PM<sub>2.5</sub> ~ 5 g/kg
- 250 heating days/year
- Concentration =  $C = E / (AER * V) =$
- $C = (\text{g/day}) / ((\text{\#}/\text{day}) * \text{m}^3) = \text{g}/\text{m}^3$
- ~ 200 ug/m<sup>3</sup> on heating days – 6 times WHO IT-1 Air Quality Guideline, 13x USEPA standard

This is half of  
Mongolia  
today



150,000  
stoves  
inside one  
big room lead to



The lesson is:

“Whether five people or a million people live in one room, everyone’s health is threatened by coal and wood fires inside.”

Many thanks

Publications and presentations on website

– easiest to just “google” Kirk R. Smith