COOKFIRES, CLIMATE, AND HEALTH:

THE UNFINISHED AGENDA OF INCOMPLETE COMBUSTION

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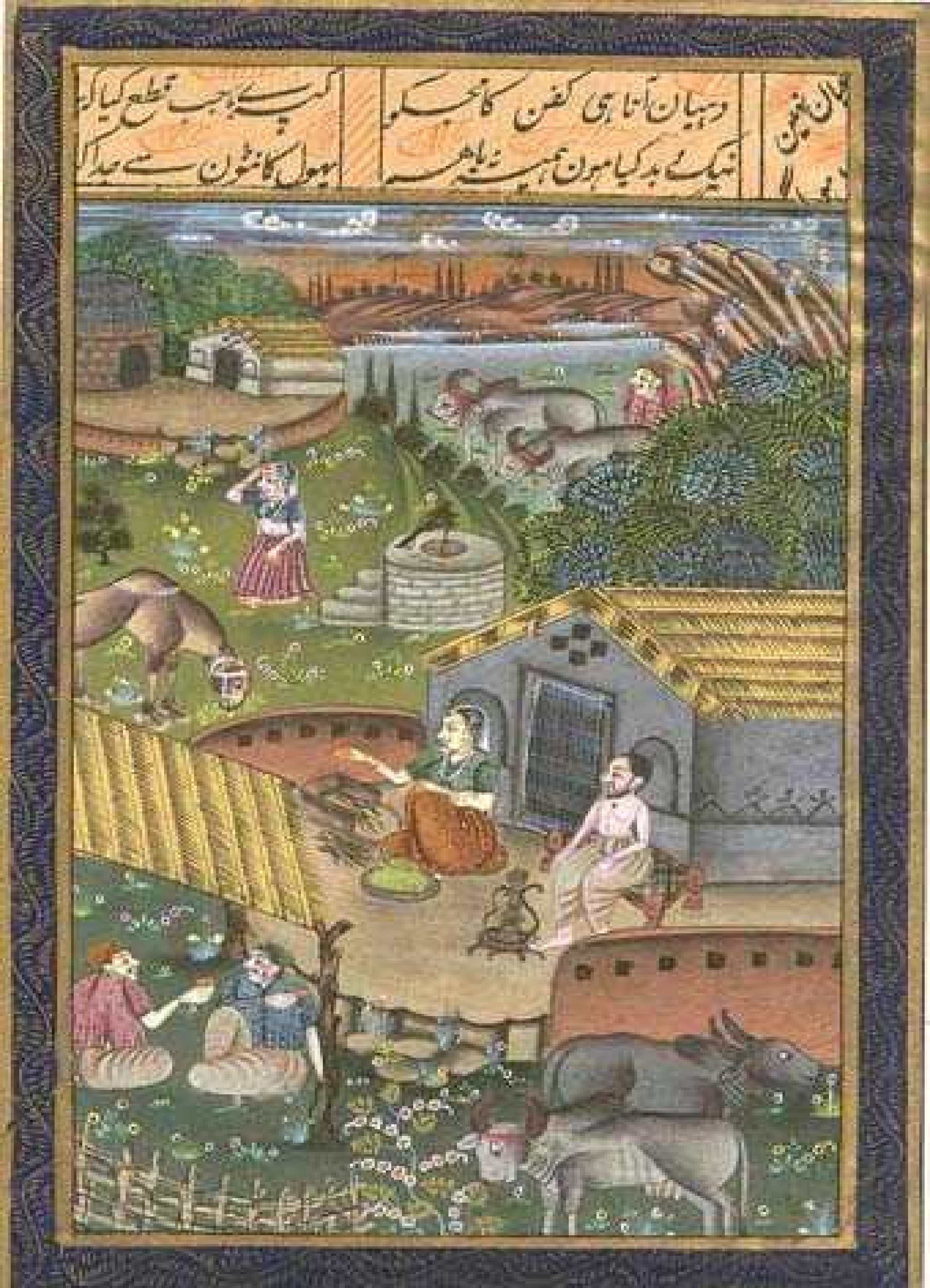
University of California Berkeley

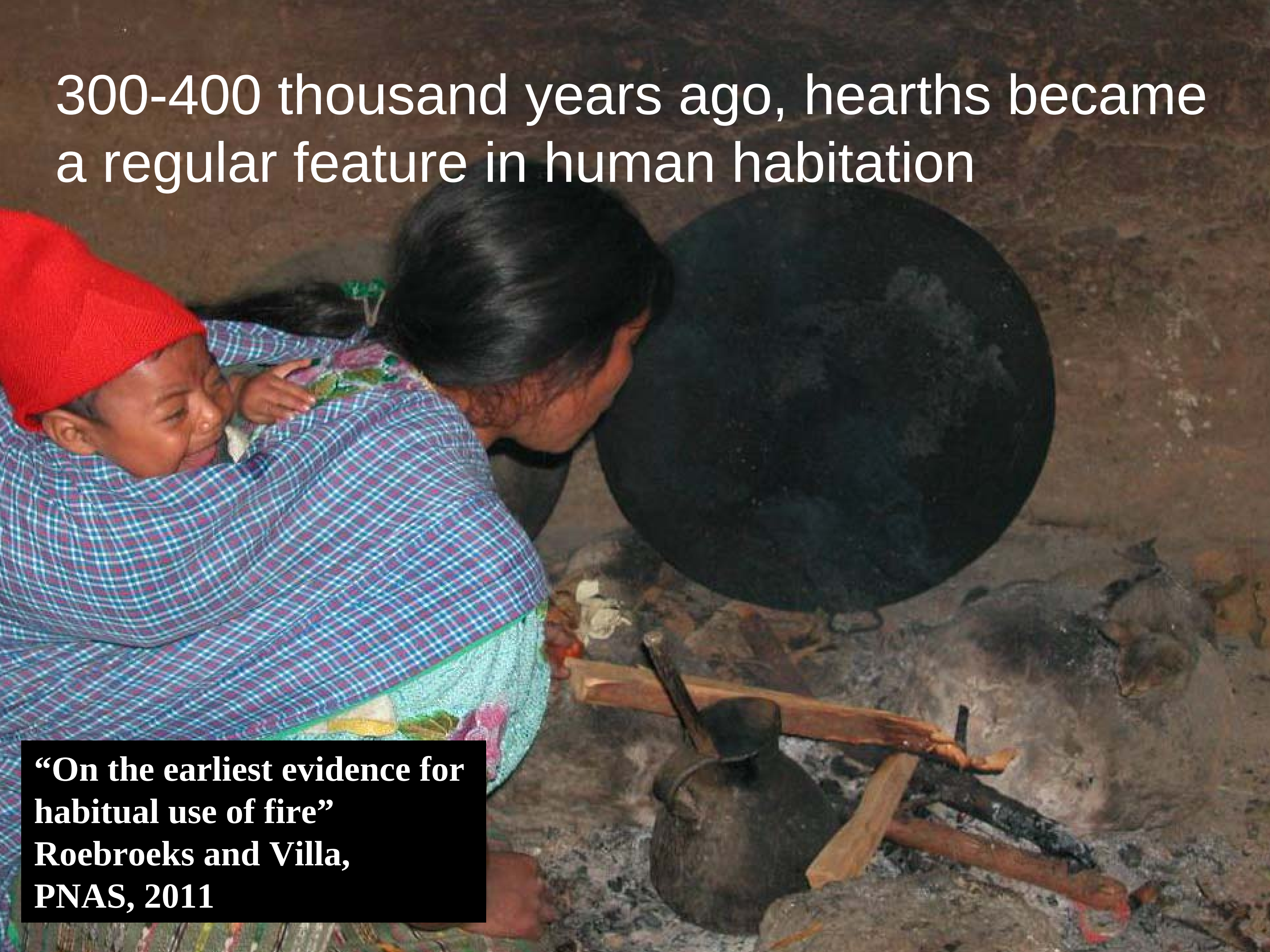
TERI University
Dehi, Sept 21, 2011



Road Map

- Why a problem?
- What health effects are found?
- What are climate implications?
- Importance of monitoring
- Principles for moving forward

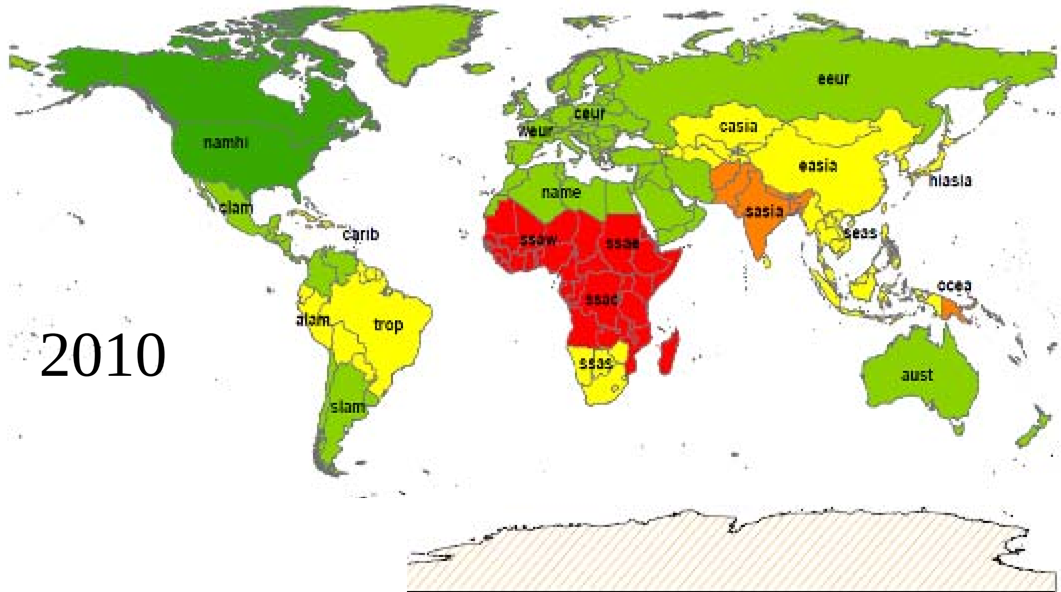
300-400 thousand years ago, hearths became a regular feature in human habitation



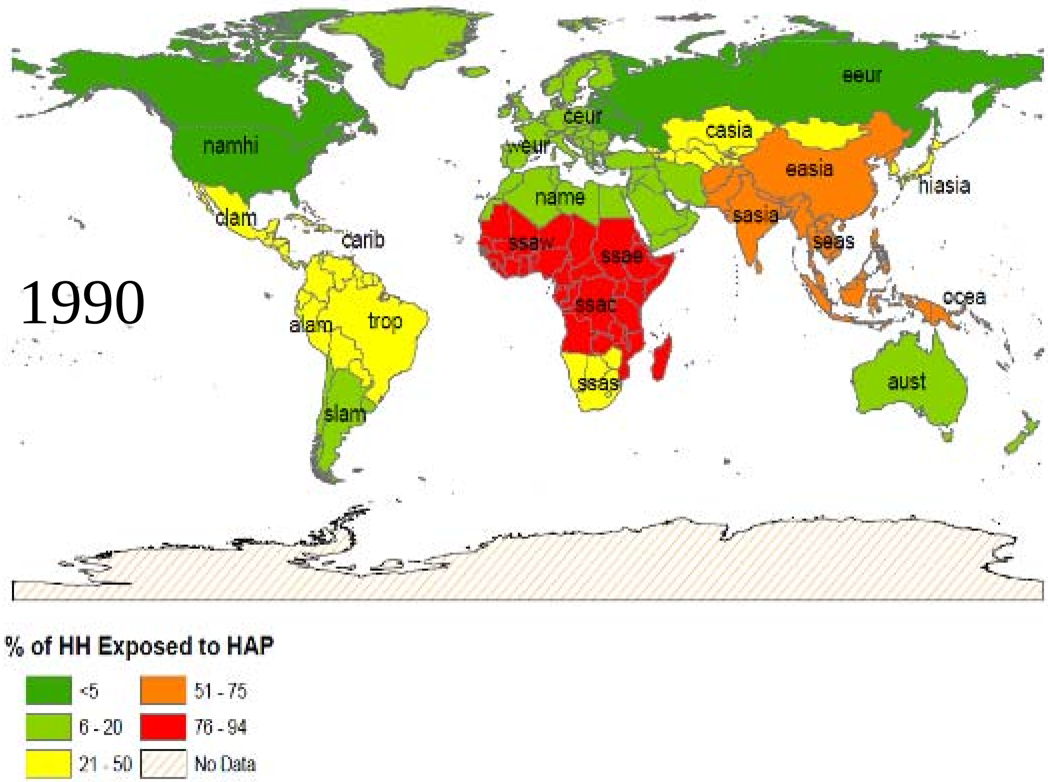
“On the earliest evidence for habitual use of fire”
Roebroeks and Villa,
PNAS, 2011

Households using biomass or coal to cook

2010



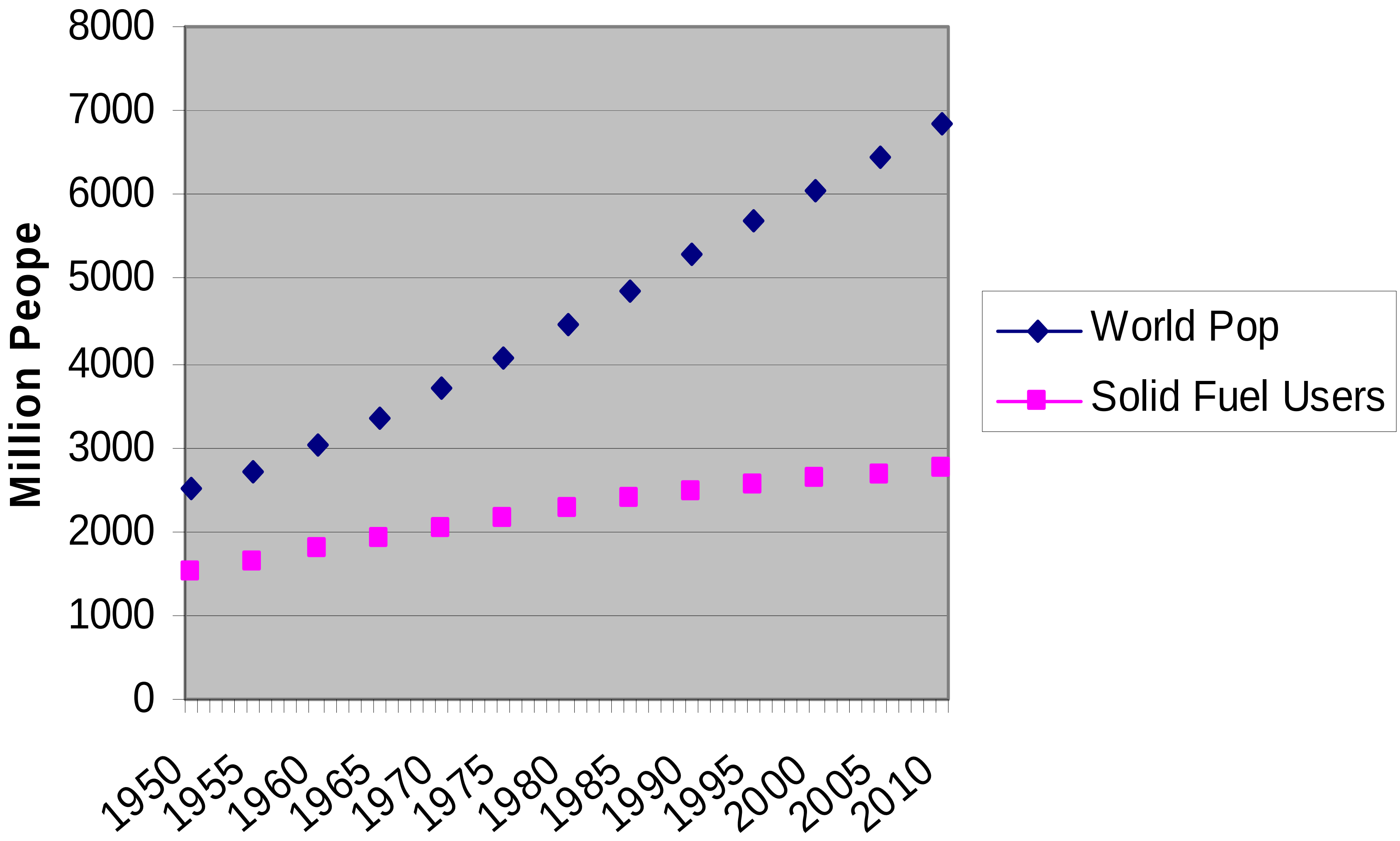
1990



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


The three major solid fuels

World Population Using Solid Fuels



Biomass Cooking in History

- **Today, ~43% use solid fuels, about 3 billion people**
- **Although the percentage is dropping, the absolute number is still rising.**
- **Perhaps 20 million people a year are added to the total each year.**
- **Indeed, there are more people using solid fuels today for cooking than the total world population in 1950**
- **Or any year previously**

Woodsmoke is natural – how can it hurt you?

Or, since wood is mainly just carbon, hydrogen, and oxygen, doesn't it just change to CO_2 and H_2O 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

Into Pot
2.8 MJ
18%

In PIC
1.2 MJ
8%

Waste Heat
11.3 MJ
74%

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

Source: Smith, et al., 2000

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

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

- Small particles, CO, NO_2
- 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*

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

Organics known to be mutagens, immune system suppressants, severe irritants, inflammation agents, central nervous system depressants, cilia toxins, endocrine disrupters, or neurotoxins.

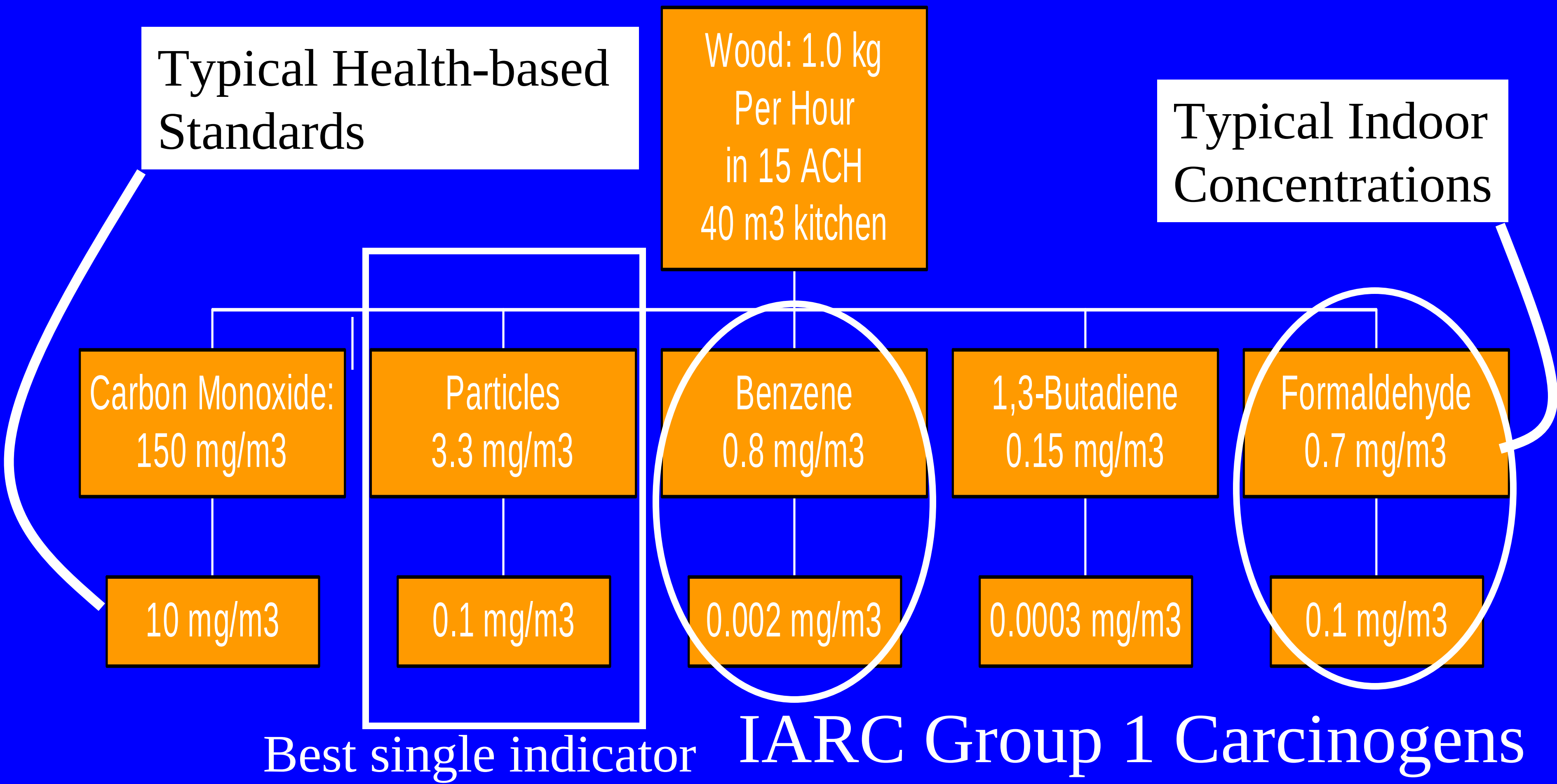
Several chemicals firmly established as human carcinogens.

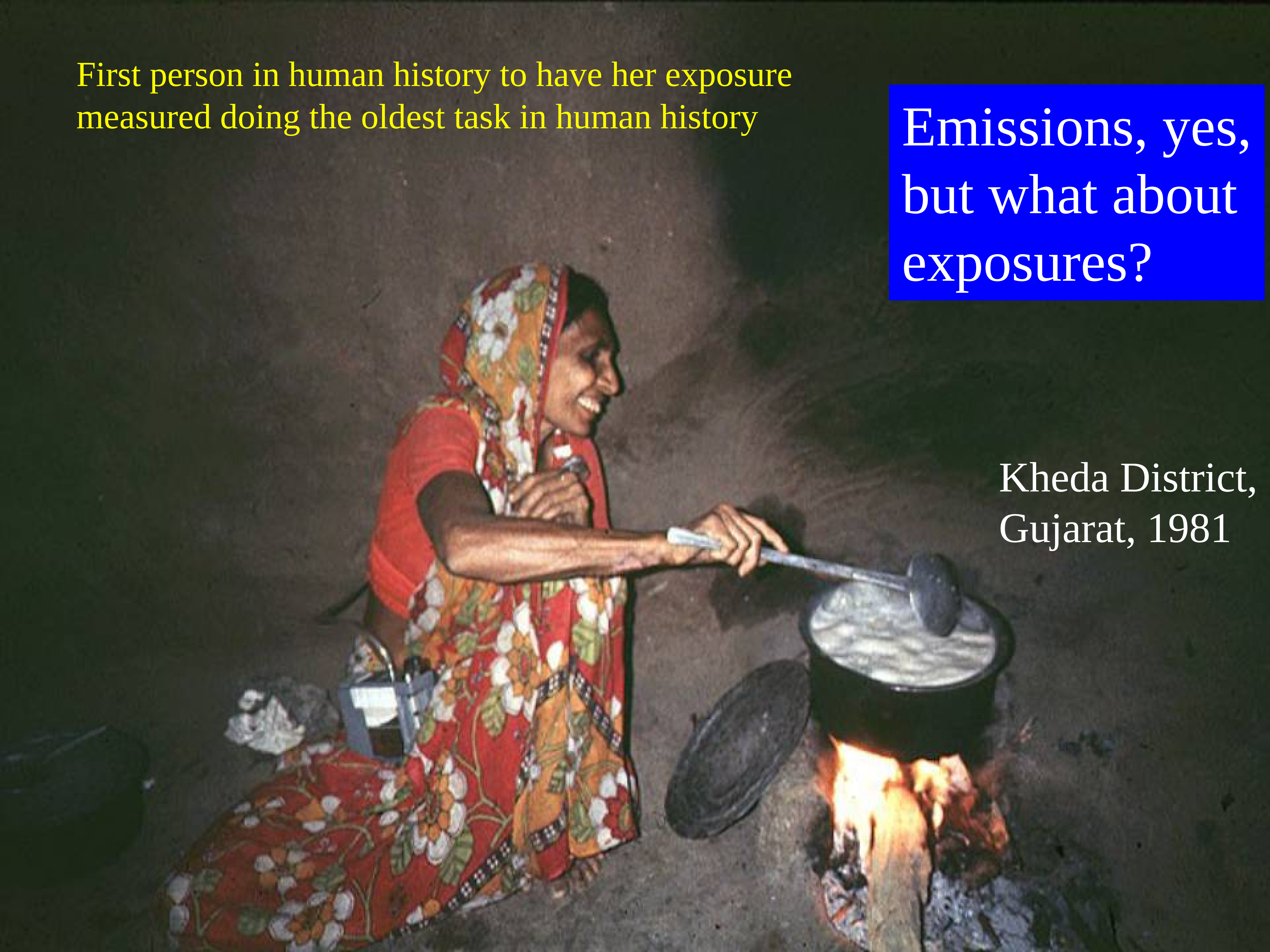
Other toxic inorganic chemicals.

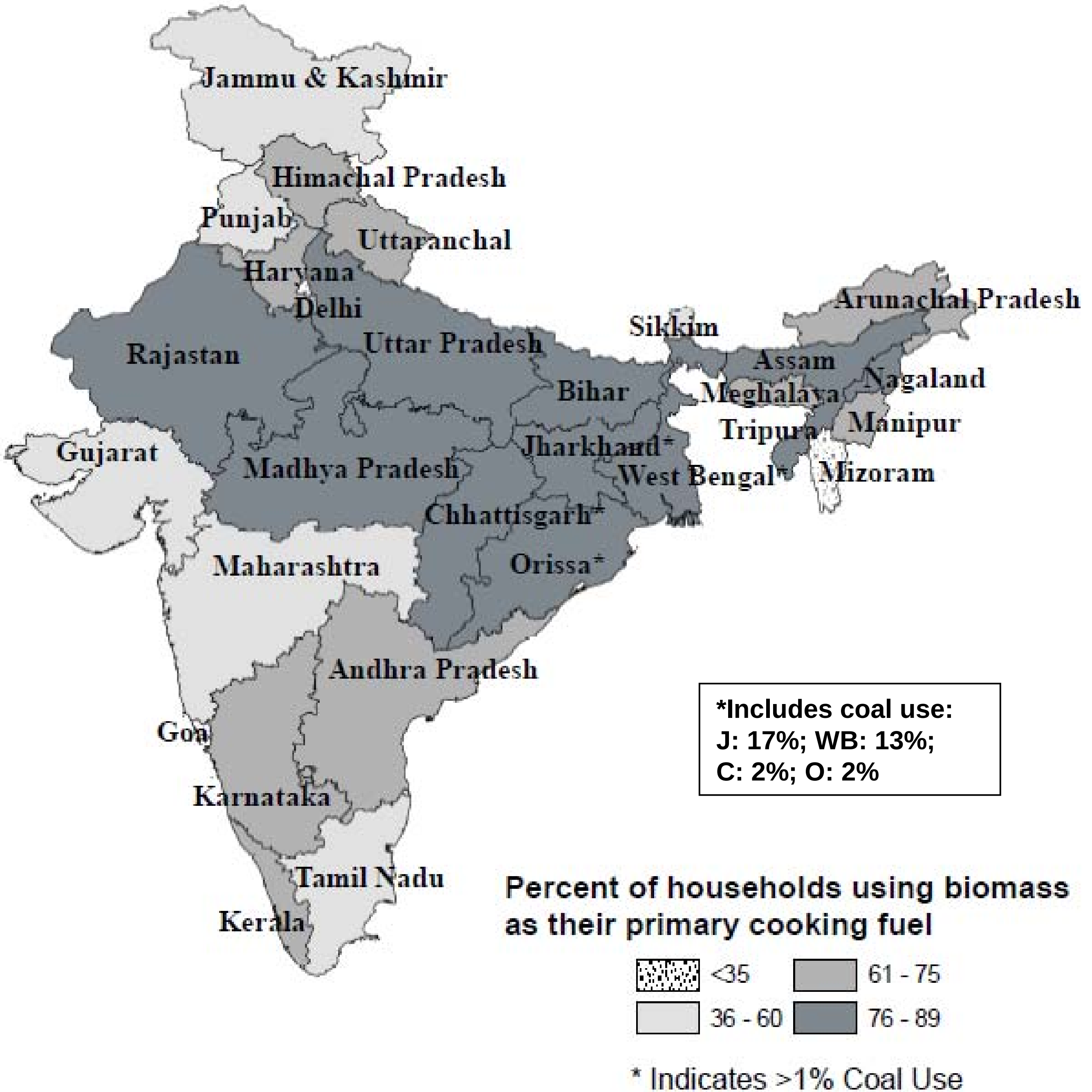
- 25+ alcohols and acids such as *methanol*
- 33+ phenols such as *catechol* & *cresol*
- Many quinones such as *hydroquinone*
- Semi-quinone-type and other radicals

- Chlorinated organics such as *methylene chloride* and *dioxin*

Health-Damaging Air Pollutants From Typical Woodfired Cookstove in India.




First person in human history to have her exposure measured doing the oldest task in human history
Emissions, yes, but what about exposures?
Kheda District, Gujarat, 1981

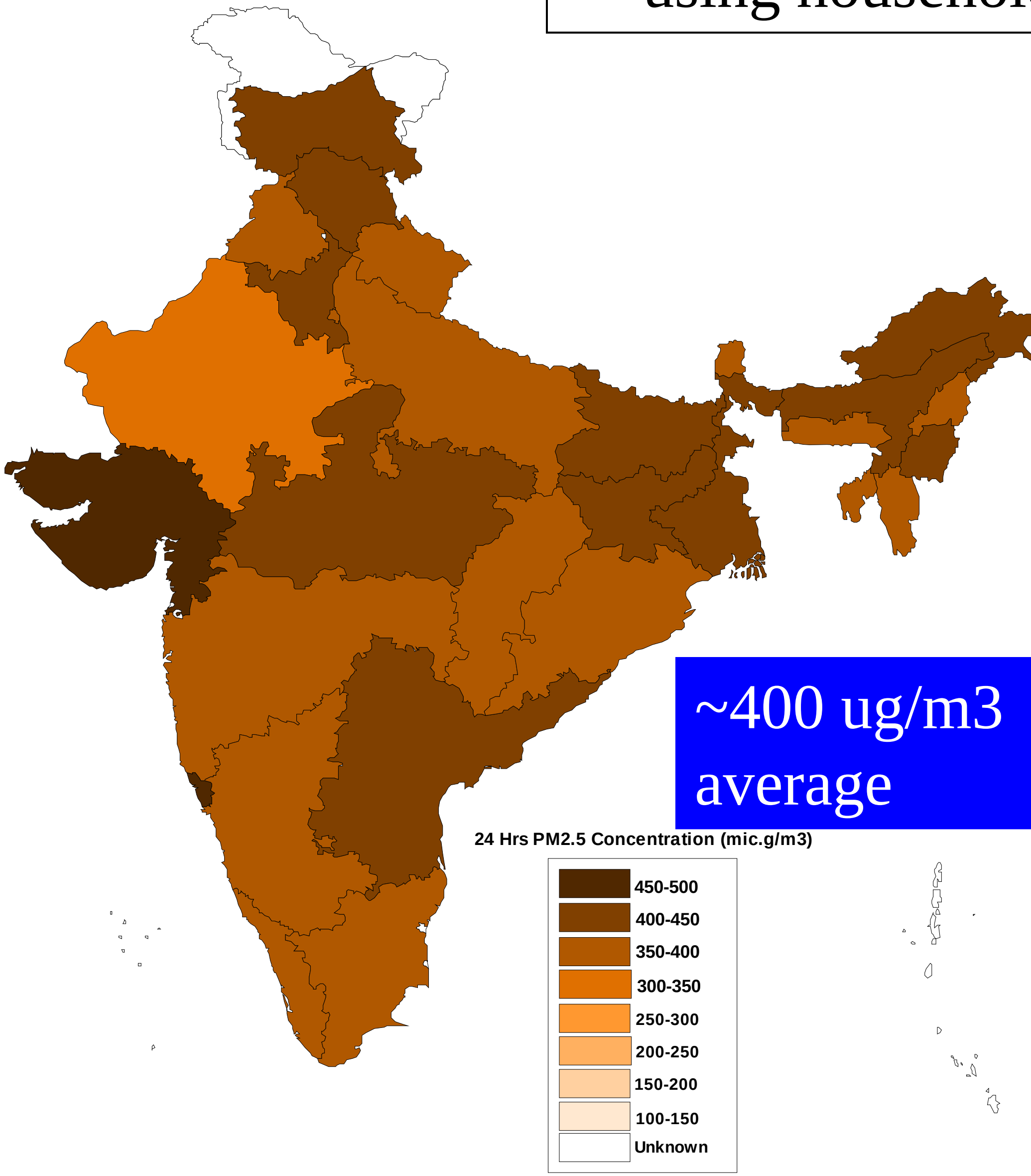


India in 2005

71% households use solid fuel for cooking

Venkataraman et al. 2010

Estimated PM2.5 for solid fuel using households in India



~400 ug/m3 average

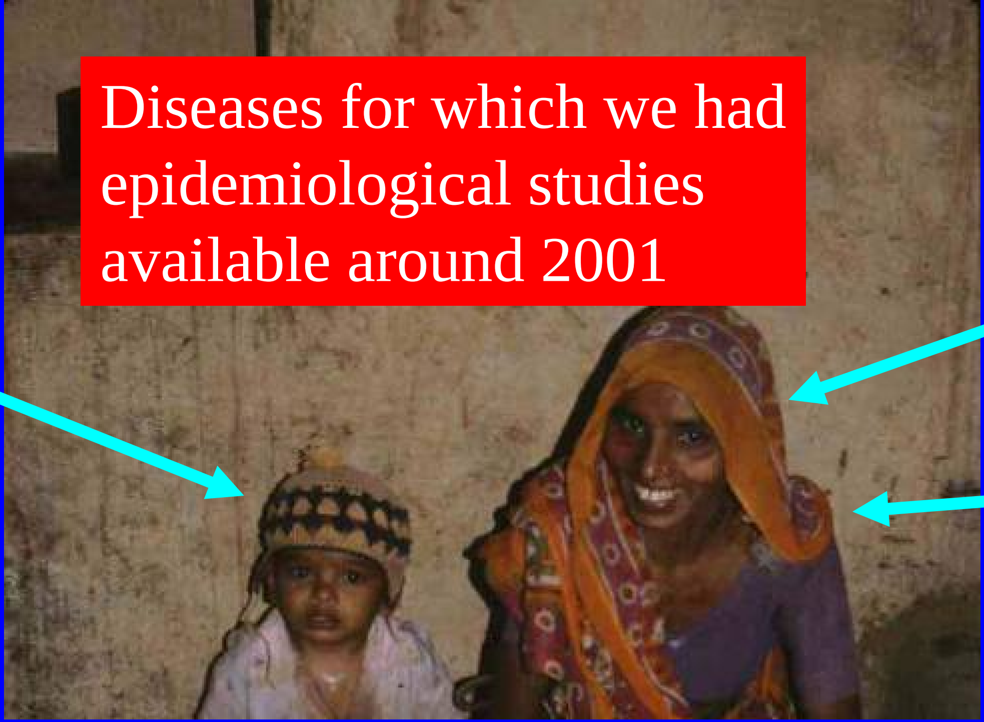
USEPA Standard
15 ug/m3

WHO Guideline
10-35 ug/m3

Preliminary result from CRA

Balakrishnan et al.

Diseases for which we had epidemiological studies available around 2001

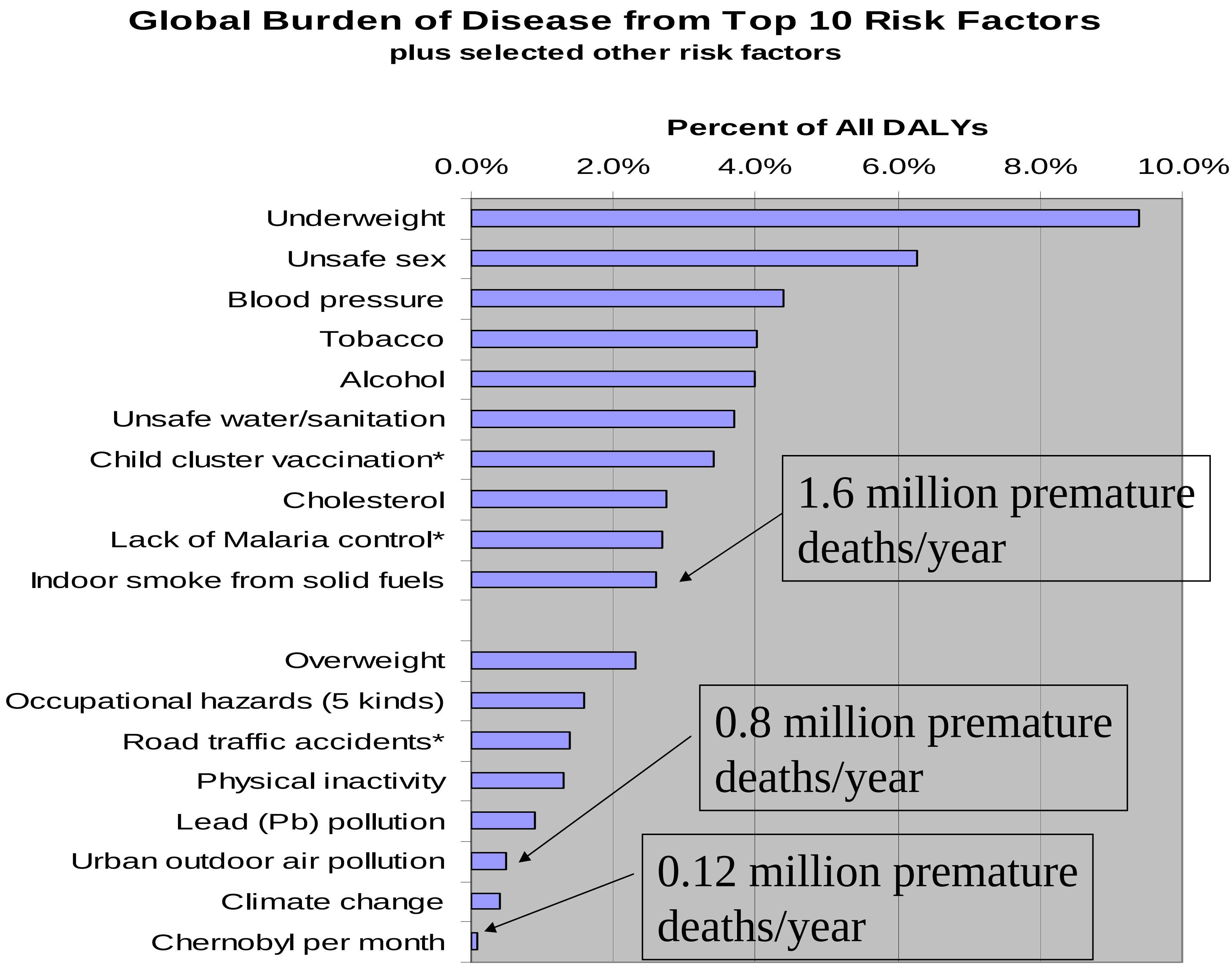


ALRI/
Pneumonia

Chronic obstructive lung disease

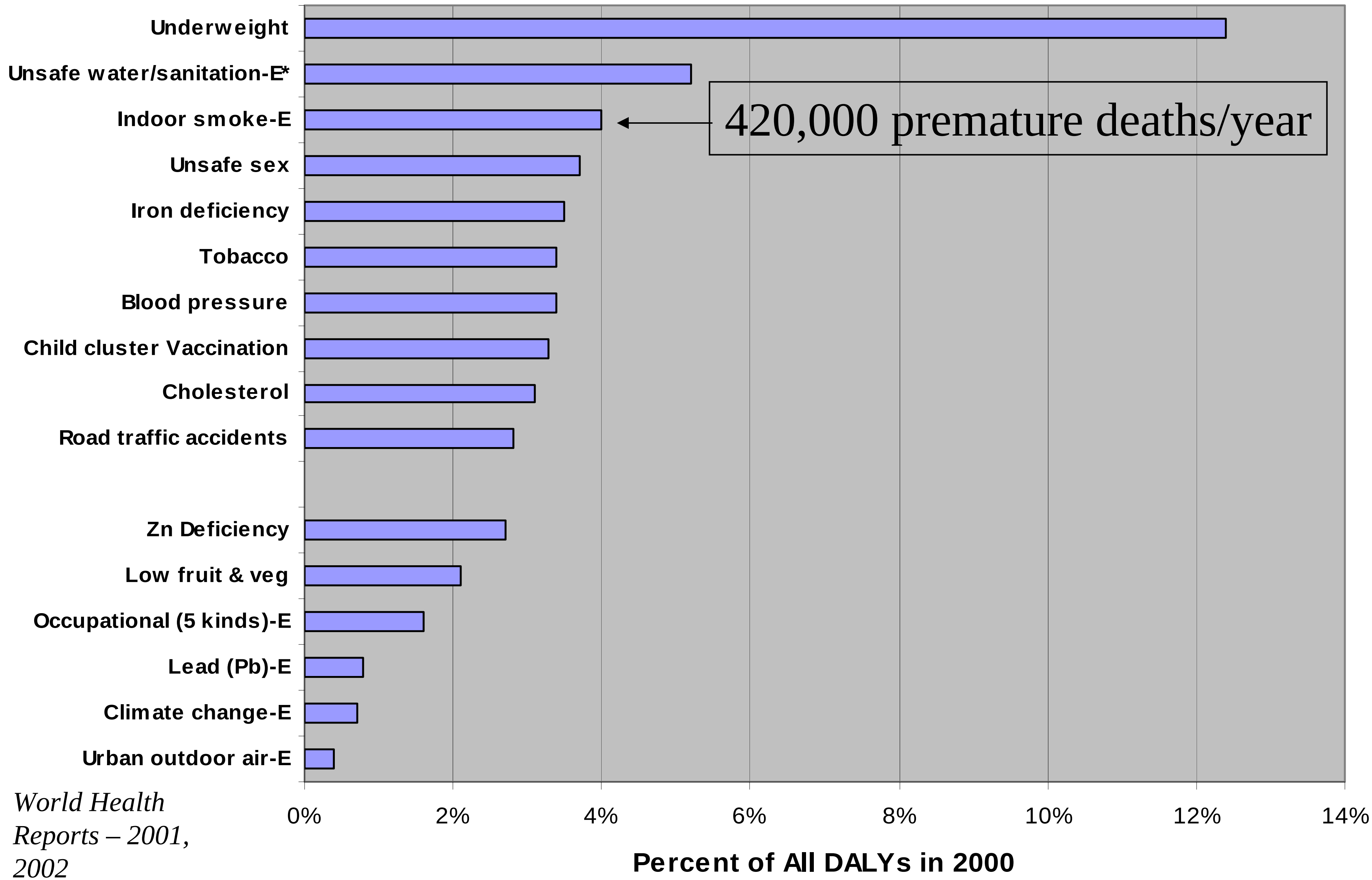
Lung cancer from coal only

Three outcomes qualified with sufficient evidence to be included in the WHO CRA of 2004

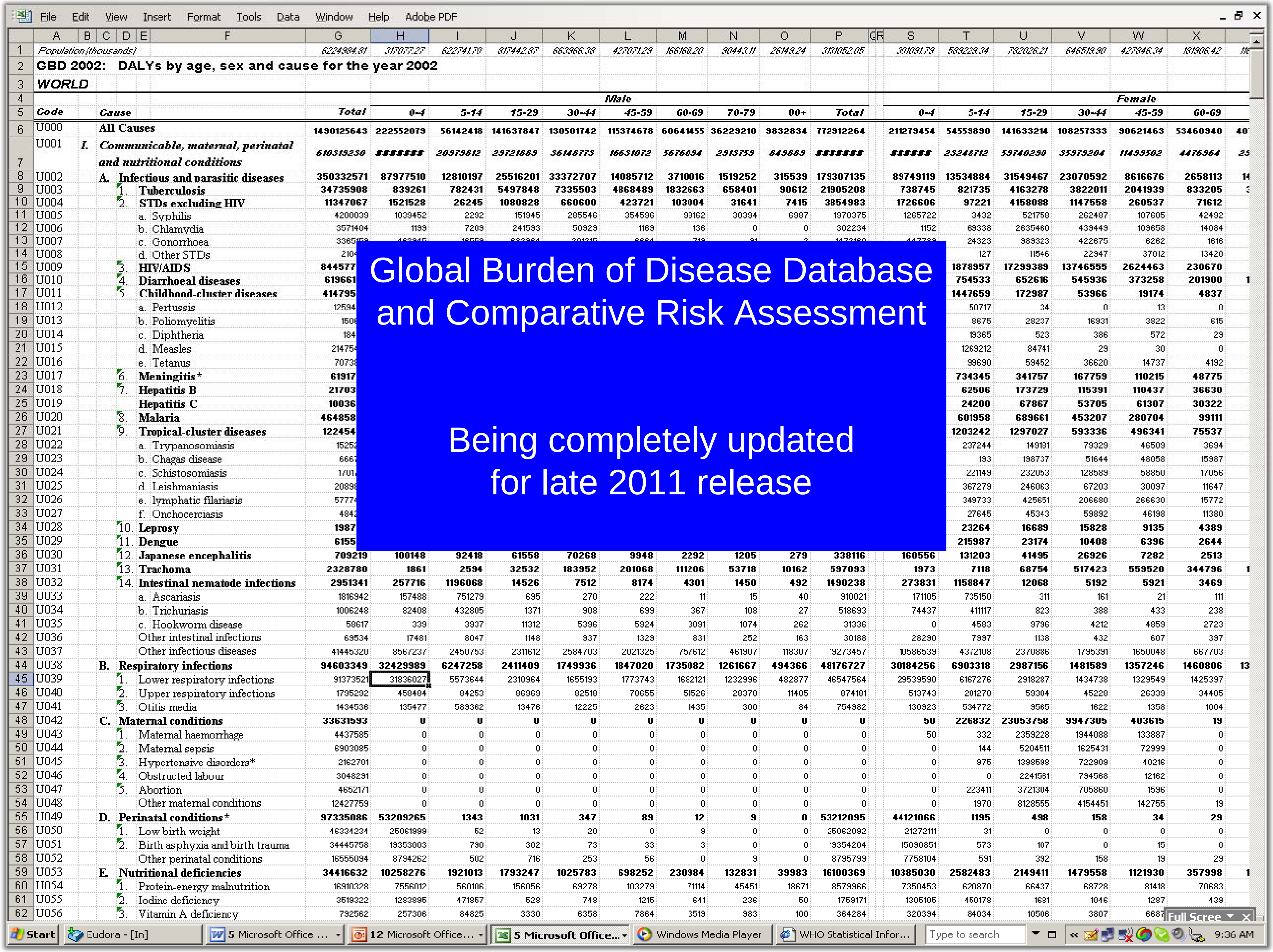

Global Burden of Disease from Top 10 Risk Factors
plus selected other risk factors
Percent of All DALYs
0.0%
2.0%
4.0%
6.0%
8.0%
10.0%
Underweight
Unsafe sex
Blood pressure
Tobacco
Alcohol
Unsafe water/sanitation
Child cluster vaccination*
Cholesterol
Lack of Malaria control*
Indoor smoke from solid fuels
Overweight
Occupational hazards (5 kinds)
Road traffic accidents*
Physical inactivity
Lead (Pb) pollution
Urban outdoor air pollution
Climate change
Chernobyl per month
1.6 million premature deaths/year
0.8 million premature deaths/year
0.12 million premature deaths/year

Indian Burden of Disease from Top 10 Risk Factors

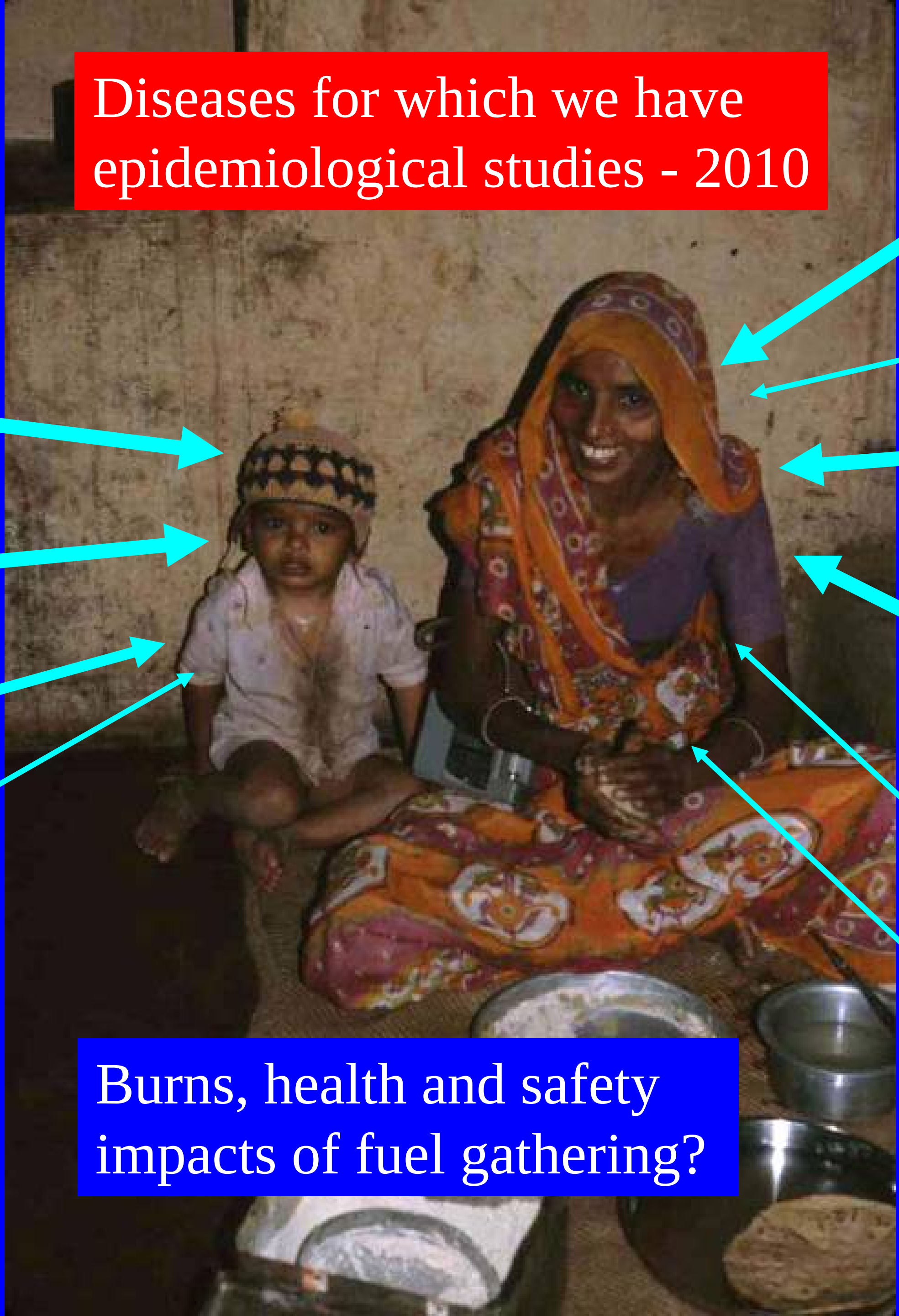
and Selected Other Risk Factors



World Health Reports – 2001, 2002


GBD 2002: DALYs by age, sex and cause for the year 2002
WORLD
Global Burden of Disease Database and Comparative Risk Assessment
Being completely updated for late 2011 release

Diseases for which we have epidemiological studies - 2010



ALRI/
Pneumonia
(meningitis)

Low birth weight

Stillbirth

Cognitive Impairment

Birth defects?

Asthma?

Chronic obstructive lung disease

Interstitial lung disease

Cancer
(lung, NP, cervical, aero-digestive)

Blindness
(cataracts, opacity)

Tuberculosis

Heart disease?
Blood pressure
ST-segment

Burns, health and safety impacts of fuel gathering?

Summary of Endpoints in New CRA for Household Air Pollution

- New estimates for diseases in previous CRA
  - Pneumonia in children
  - COPD in adults (male and female)
  - Lung cancer in adults (male and female)
- Diseases now included
  - Low birth weight
  - Cataracts
  - Heart disease
- Still unclear – not included
  - TB
  - Asthma
  - Other cancers

Story of Two Conferences

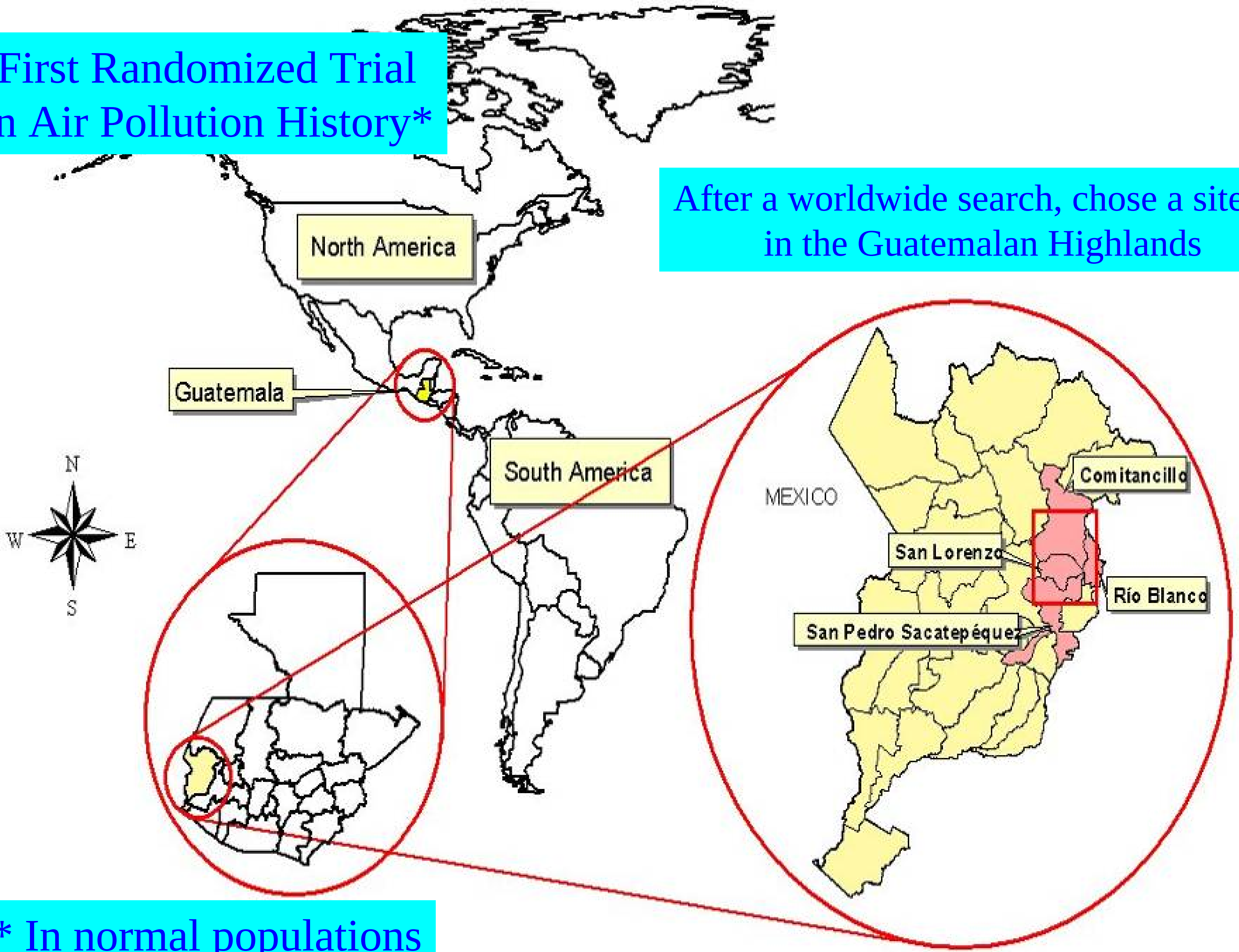
- Air pollution conference
  - High exposures to large vulnerable population
  - No more health effects work needed
- International health conference
  - Still doubt about causality
  - Need to know exact benefit to be expected
- Where are your randomized controlled trials?

History of an RCT

- ~1980: Early studies of health effects in Nepal and elsewhere
- 1981: First measurements of pollution levels in India
- 1984: International meeting to decide on needed research
  - Chose randomized control trial (RCT) of ALRI
- 1986-89: Unfunded proposals to do RCT in Nepal
- 1990: WHO establishes committee to find best sites
- 1990-1992: Criteria established and site visits made
- 1992: Highland Guatemala chosen
- 1991-1999: Pilot studies to establish data needed for proposal
- 1996-1999: Unfunded proposals
- 2001: NIEHS funding secured
- 2002-2005: Fieldwork completed
- 2011: Main results published – in press Sep
- 25+ years from deciding to conduct RCT to results!

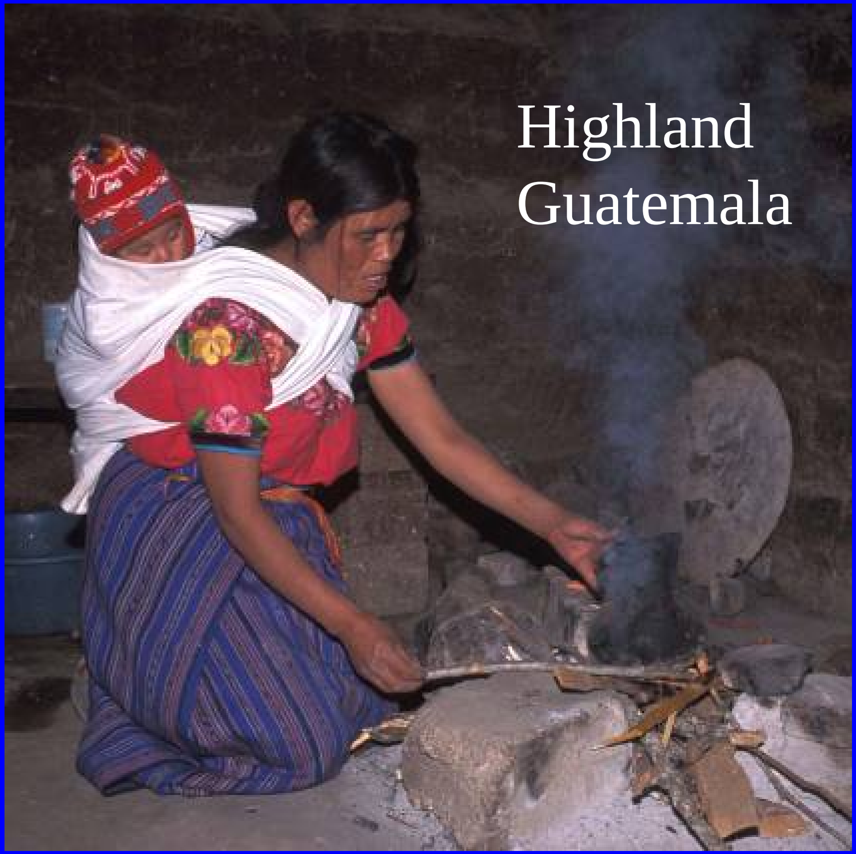
First Randomized Trial In Air Pollution History*

After a worldwide search, chose a site in in the Guatemalan Highlands



* In normal populations

RESPIRE: (Randomized Exposure Study of Pollution Indoors and Respiratory Effects)

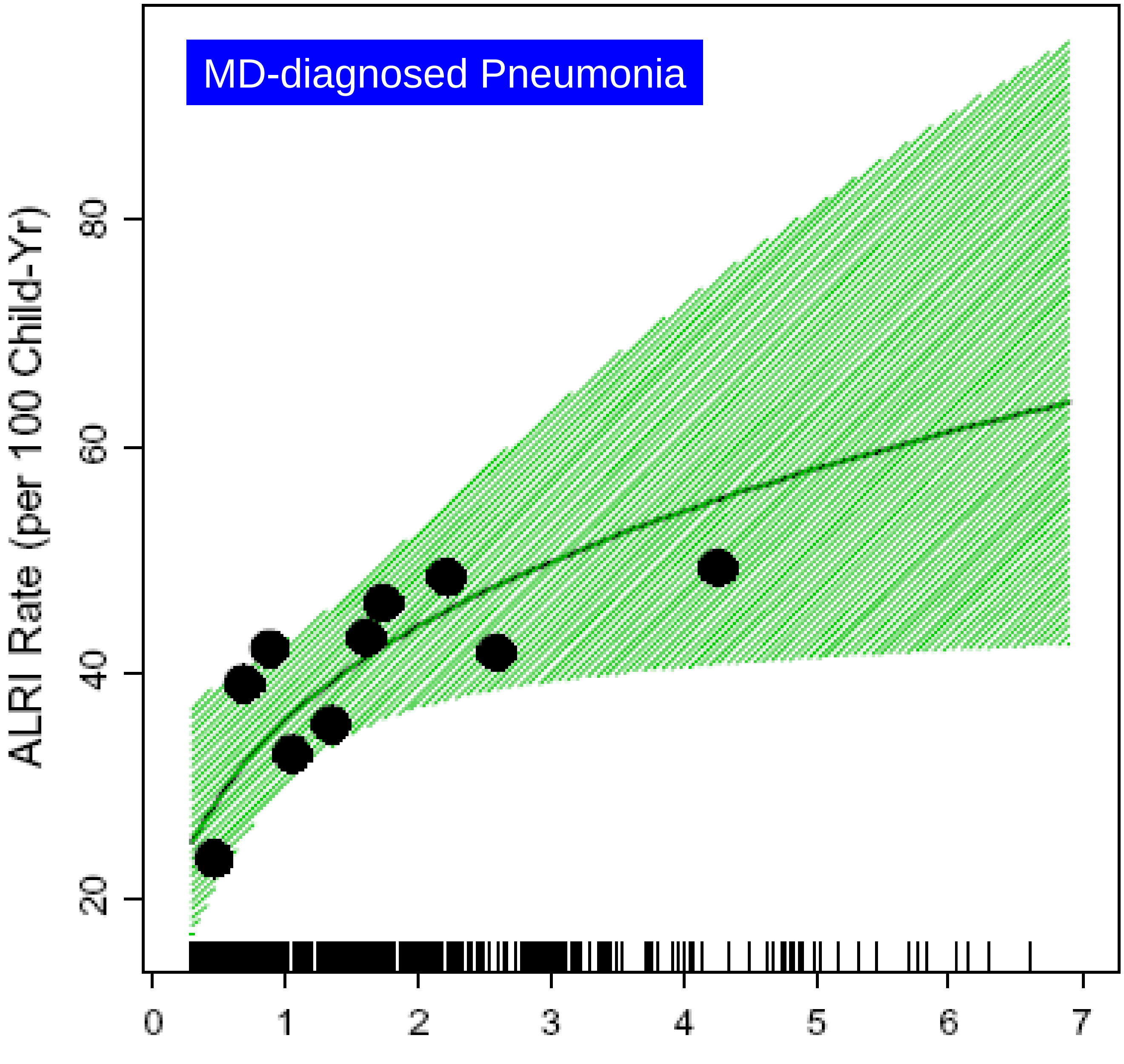


Traditional 3-stone open fire

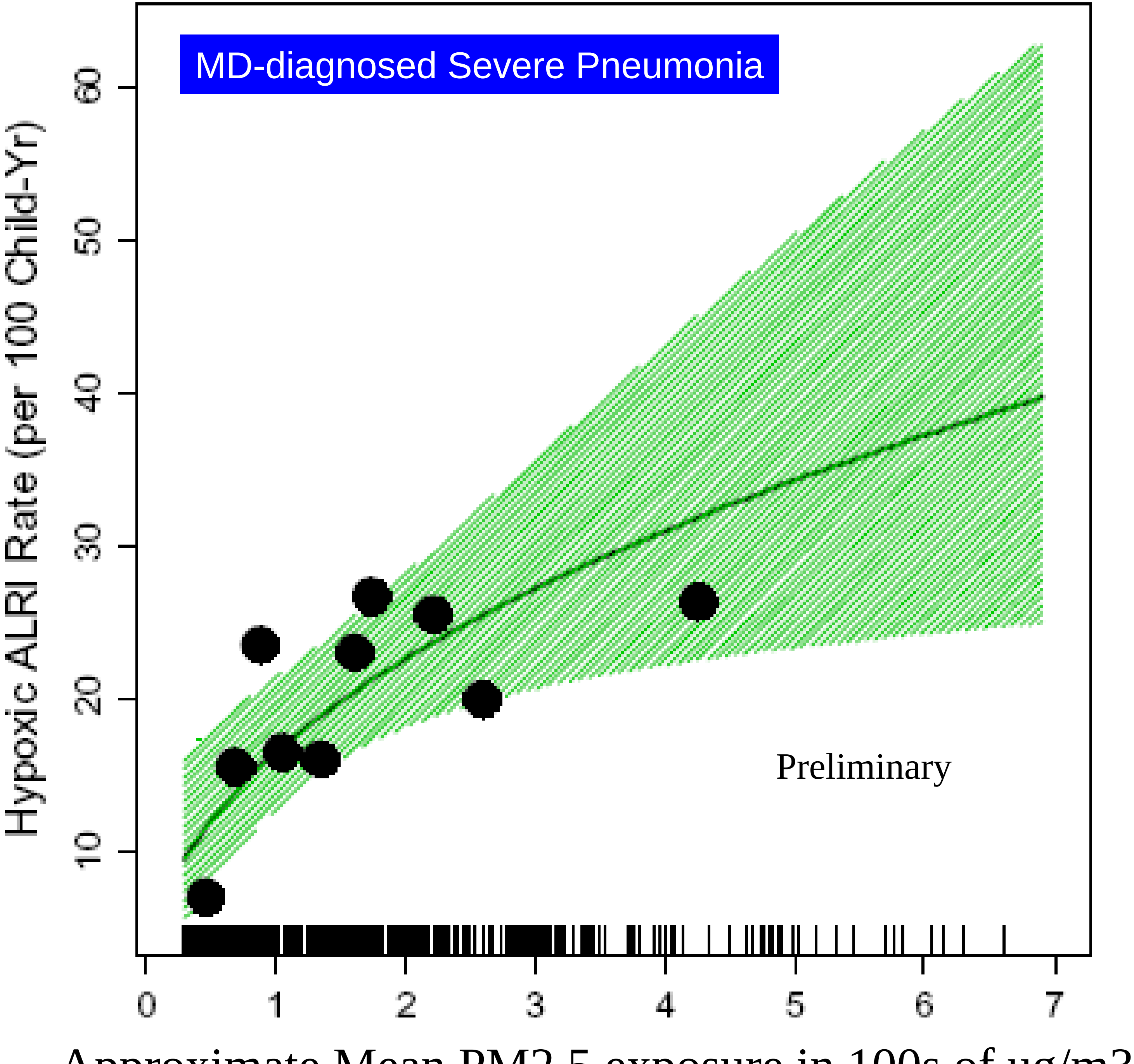
Chimney woodstove

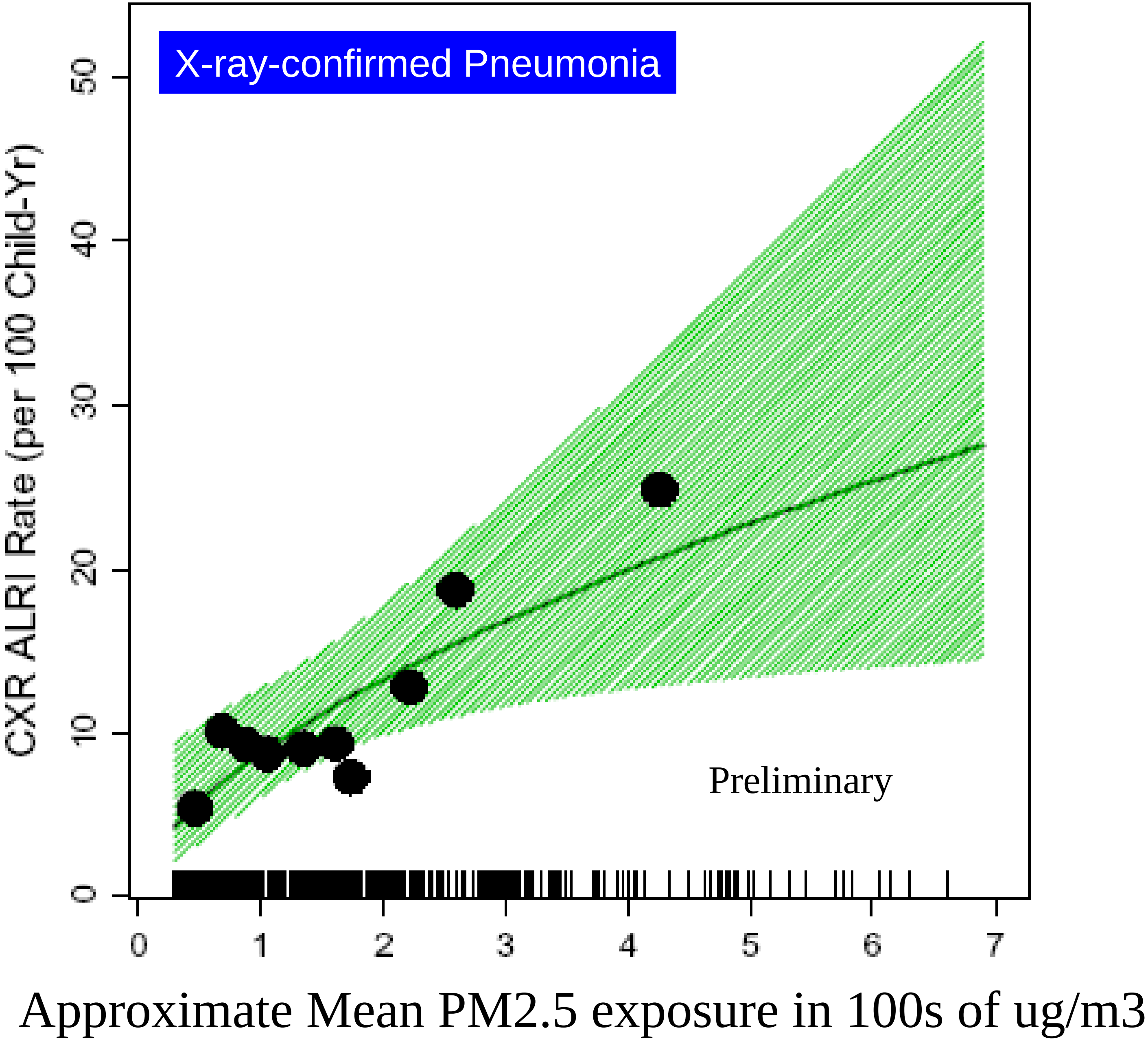

Tubito
Tubito

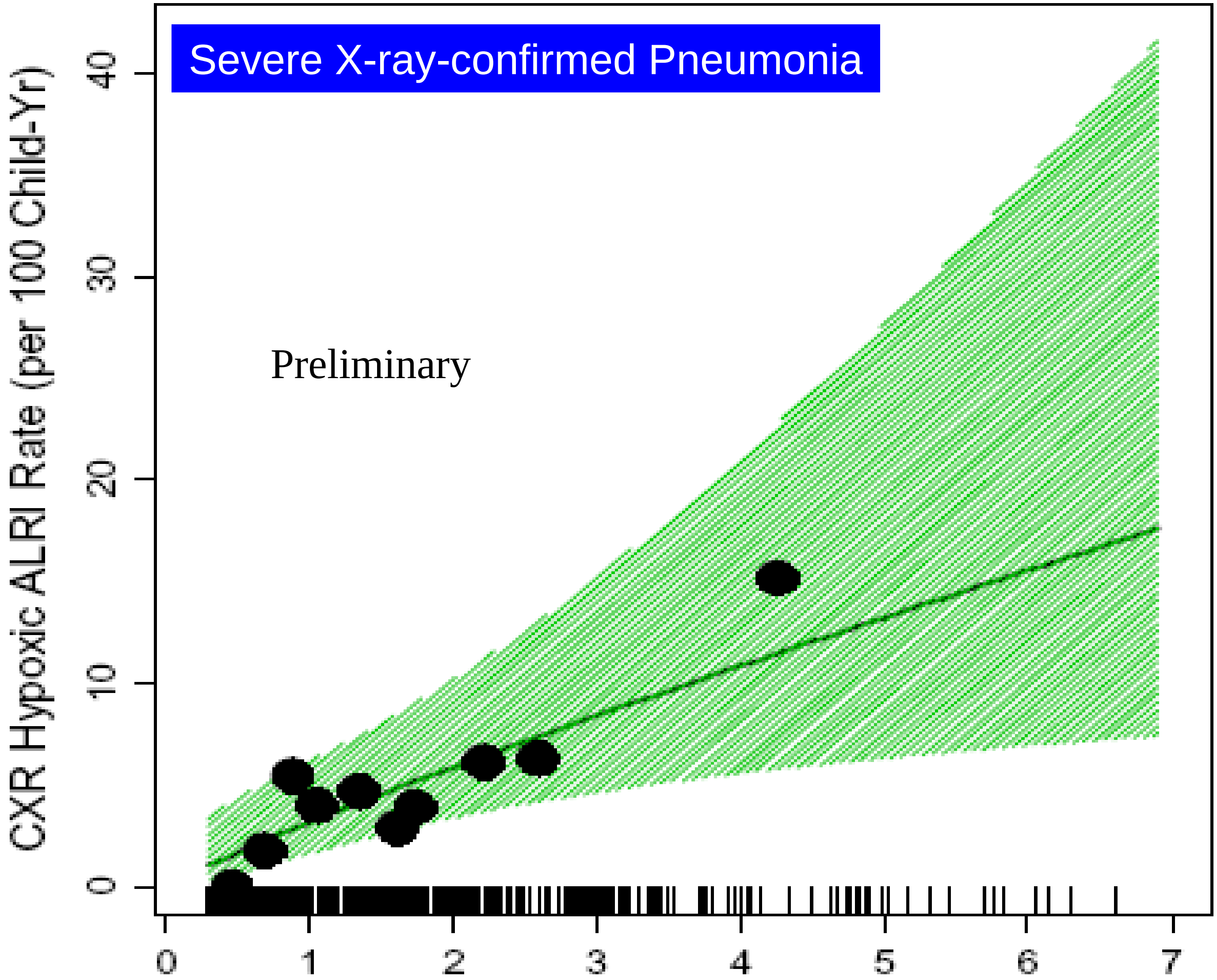
Preliminary



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


MD-diagnosed Severe Pneumonia
Hypoxic ALRI Rate (per 100 Child-Yr)
10
20
30
40
50
60
Preliminary
0
1
2
3
4
5
6
7
Approximate Mean PM2.5 exposure in 100s of ug/m3


X-ray-confirmed Pneumonia
CXR ALRI Rate (per 100 Child-Yr)
0
10
20
30
40
50
0
1
2
3
4
5
6
7
Preliminary
Approximate Mean PM2.5 exposure in 100s of ug/m3

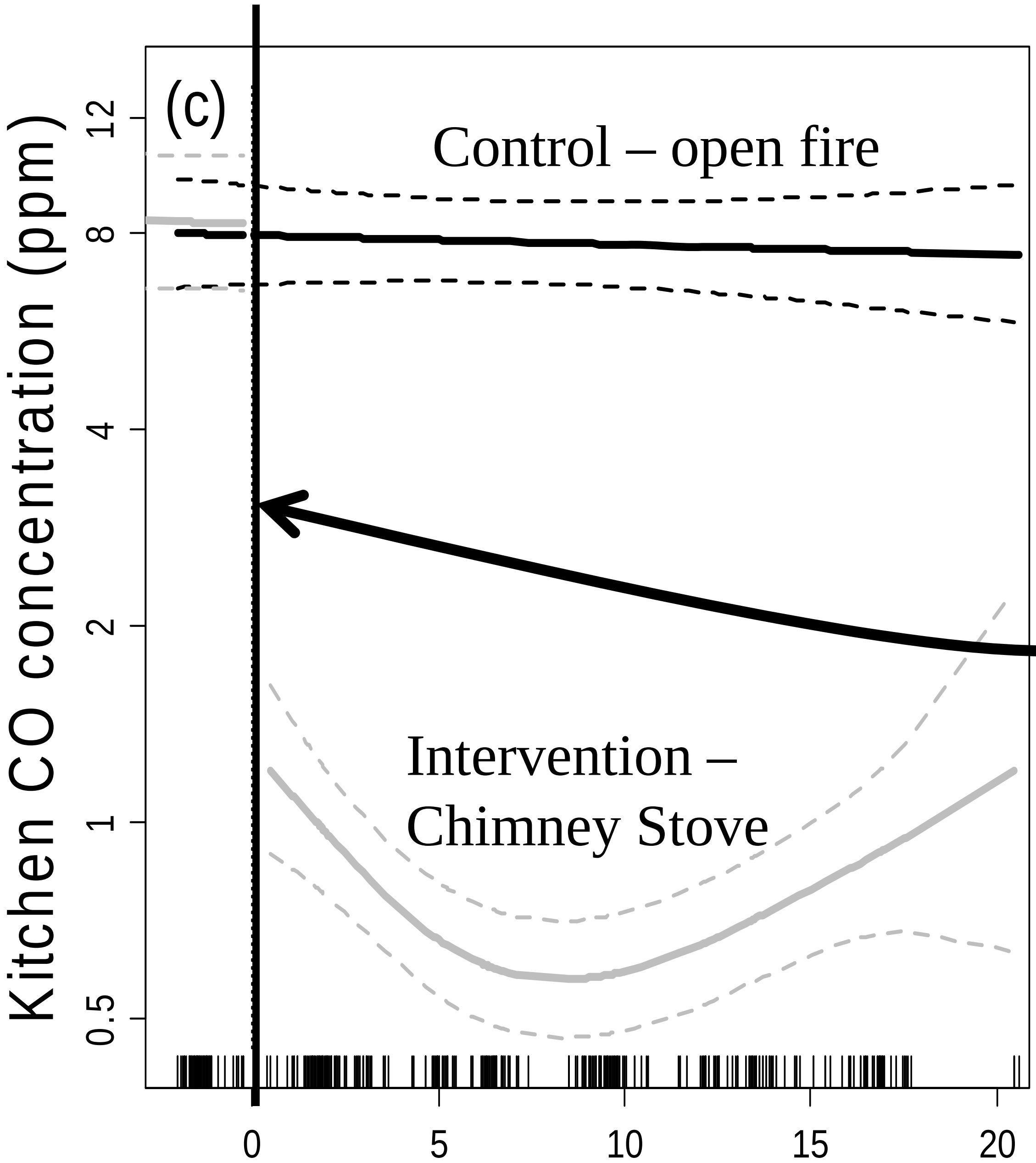


Approximate Mean PM2.5 exposure in 100s of ug/m3

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



Effect of
Chimney
Stove
On
Kitchen CO
Levels

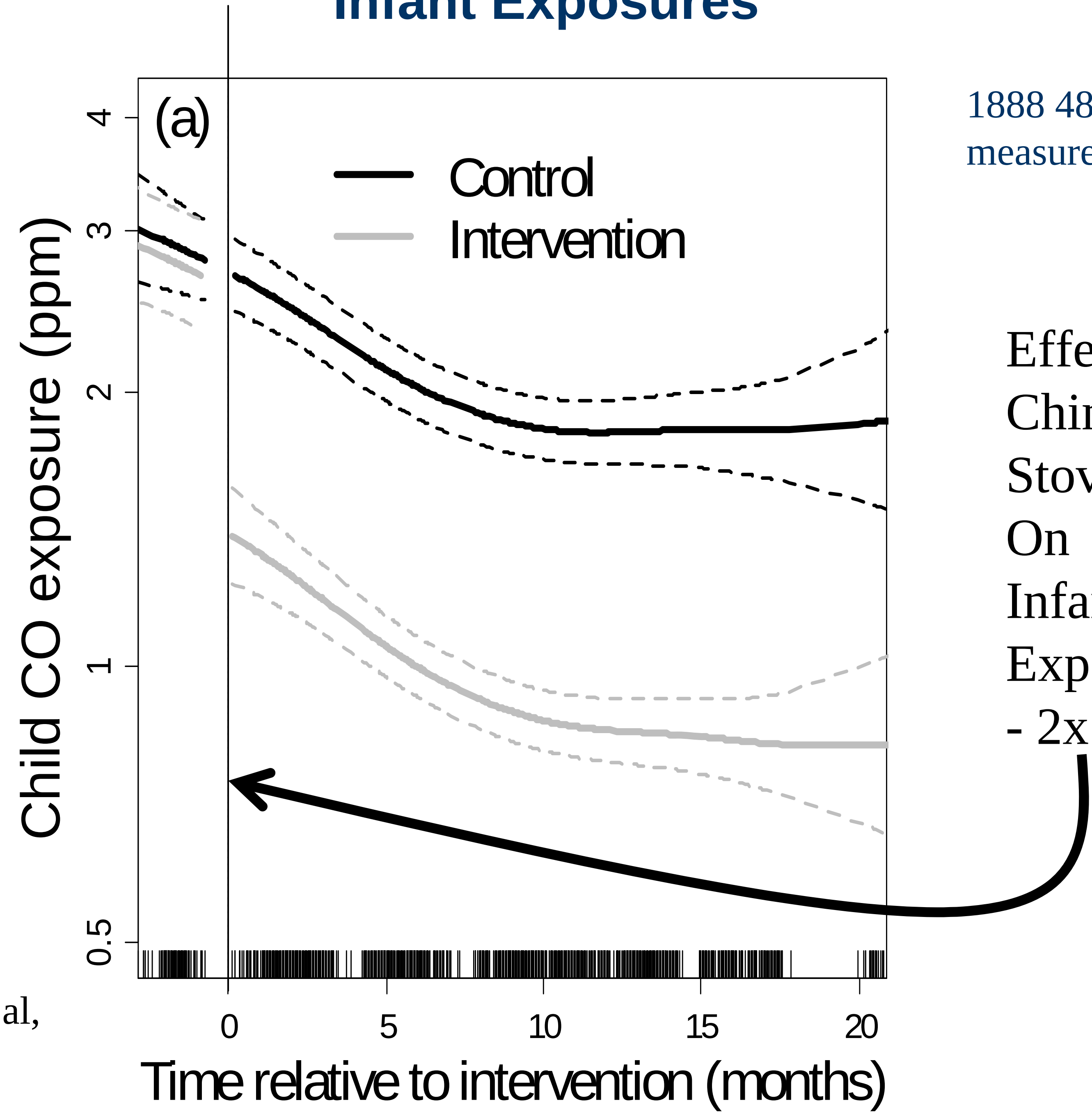
Factor
of ~10 less

285 48-h
measurements

Months

Smith, et al,
2010

Infant Exposures



1888 48-h measurements

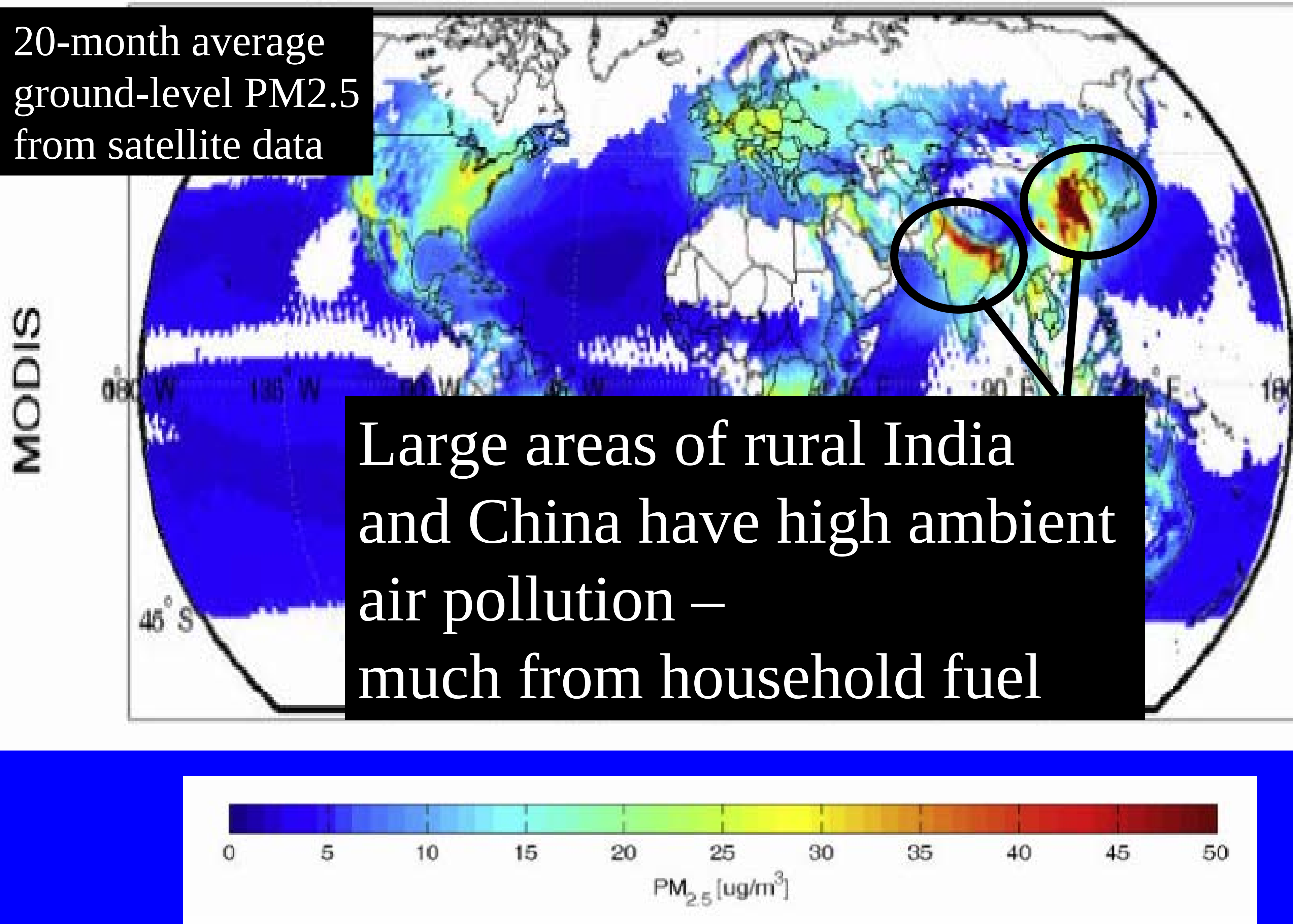
Effect of Chimney Stove On Infant Exposures - 2x less

Smith, et al, 2010

Reasons that child personal exposures did not lower as much as kitchen levels:

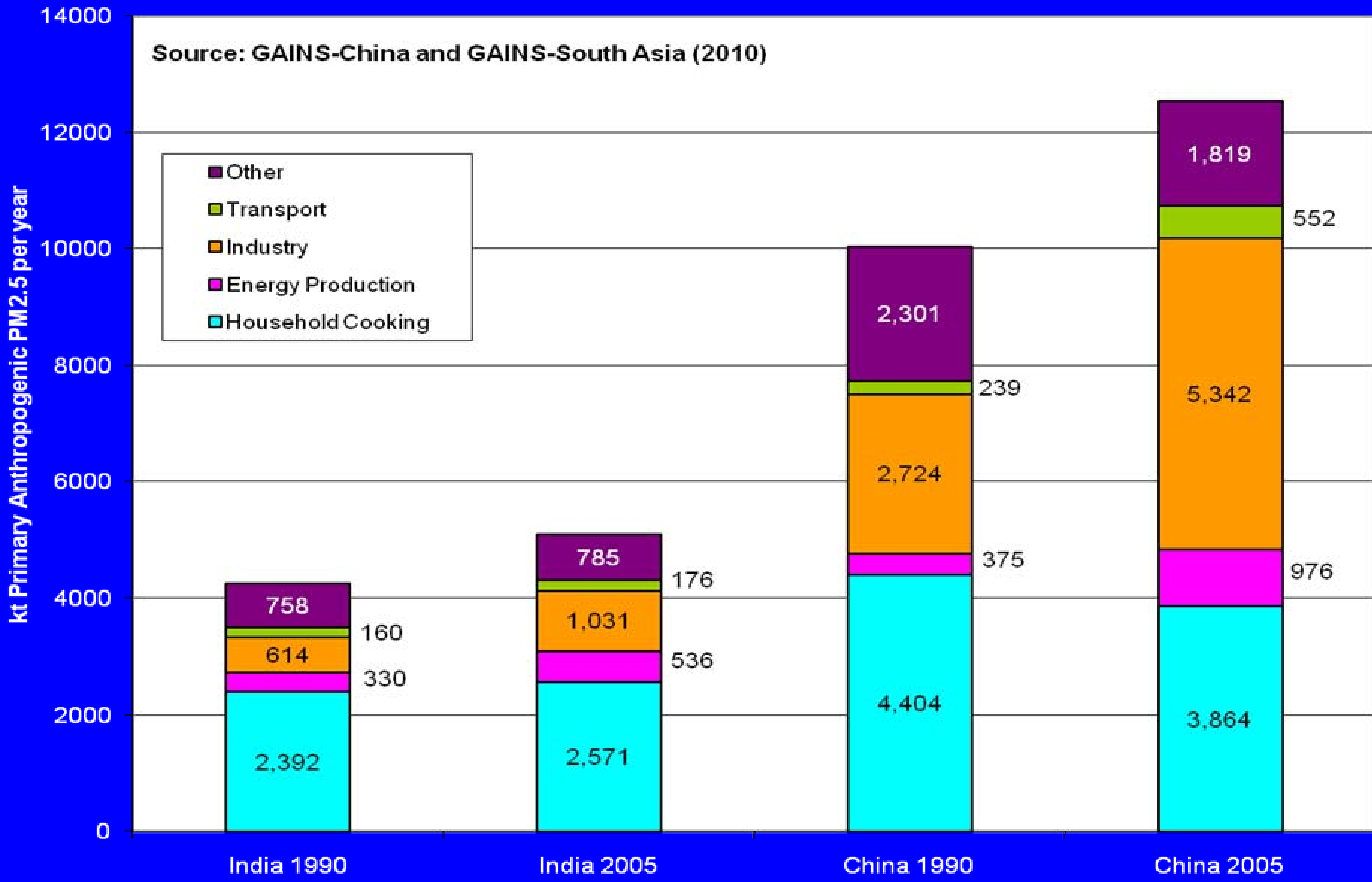
- --Time-activity: the kids do not spend their entire day in the kitchen
- --Household (or “neighborhood”) pollution: a chimney does not reduce smoke, but just shifts it outside into the household environment, where the difference between intervention and control households was less
- --Other burning around house not different

20-month average ground-level PM2.5 from satellite data



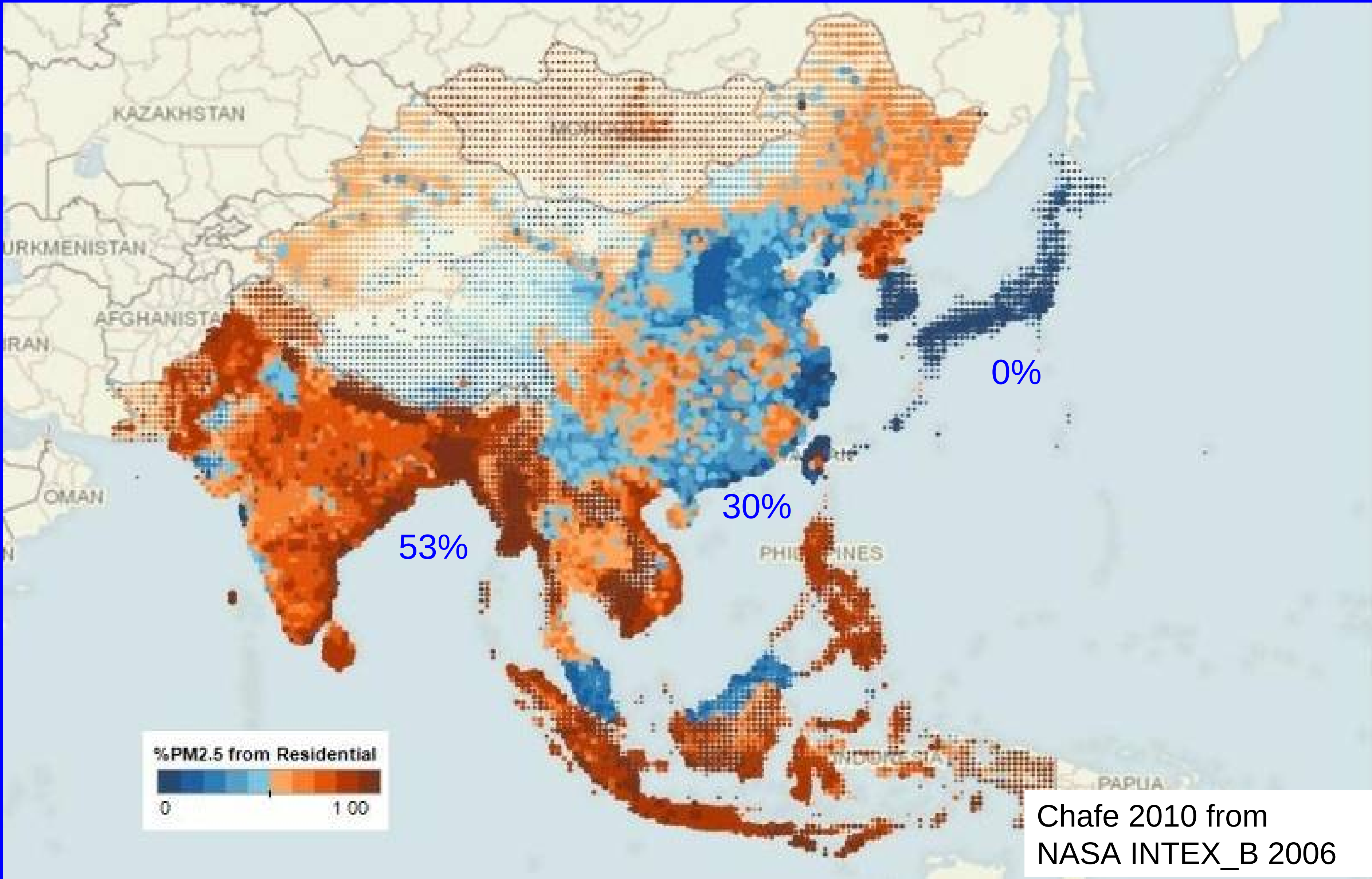
Large areas of rural India and China have high ambient air pollution –
much from household fuel

Sources of Primary $PM_{2.5}$: India and China



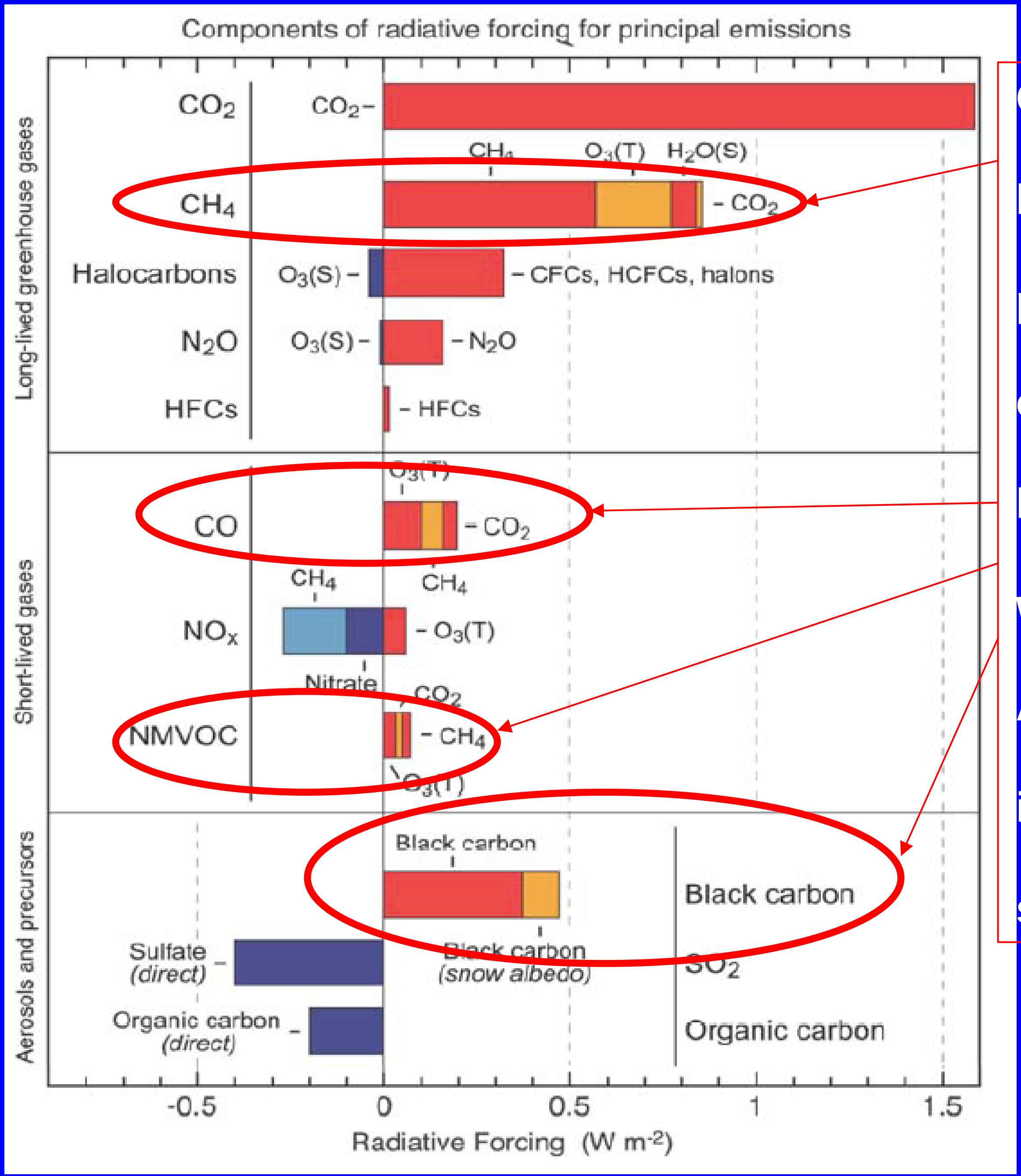
IIASA, 2010

NASA INTEX_B Database
Percent $PM_{2.5}$ emissions from households



Chafe 2010 from
NASA INTEX_B 2006

Global warming in 2005 due to all human emissions since 1750

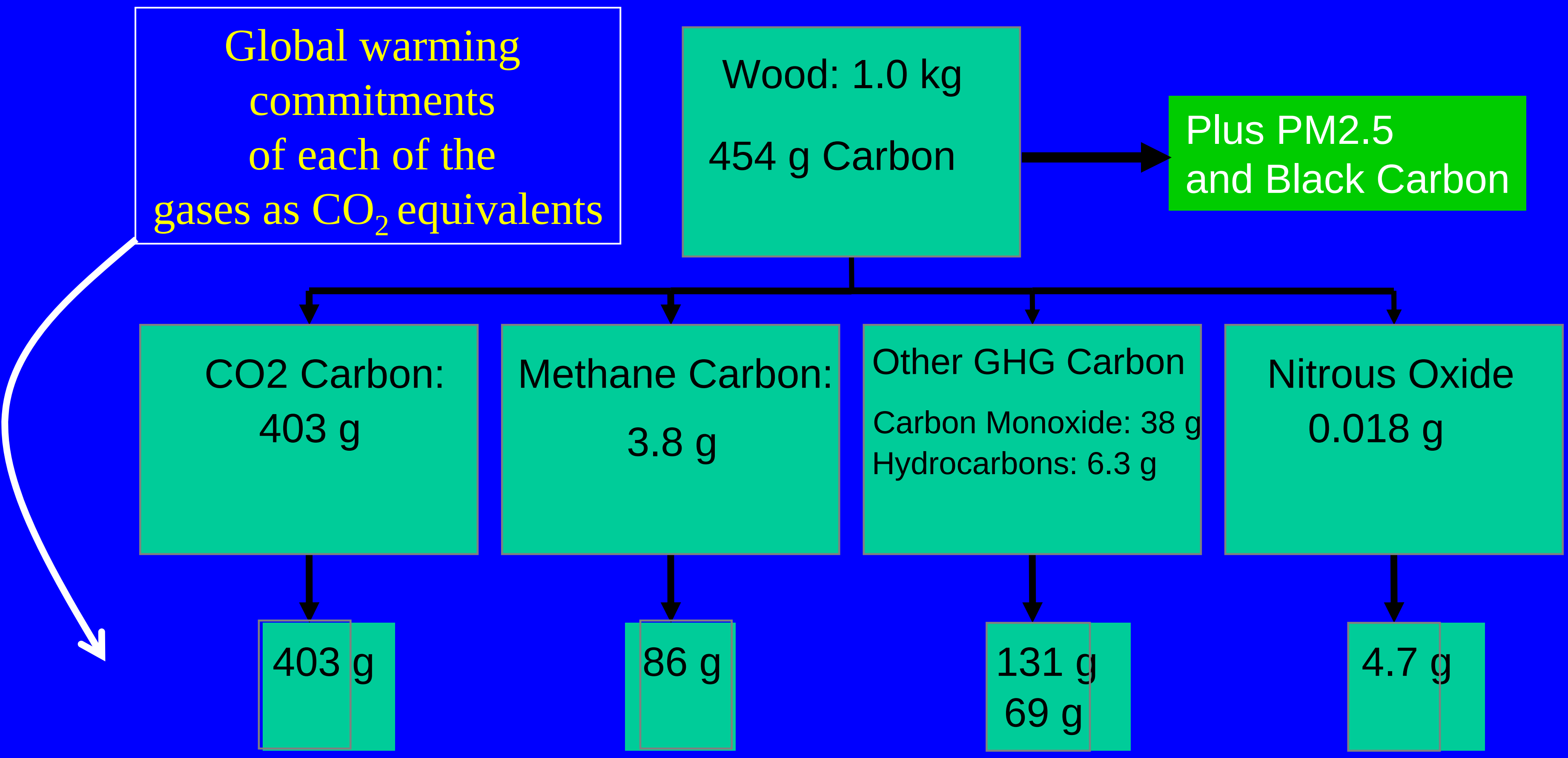


CO_2 is important for climate, but so are many other pollutants, including the ones circled that, unlike CO_2, also have significant health as well as climate impacts

All of these are products of incomplete combustion, in some cases the only source

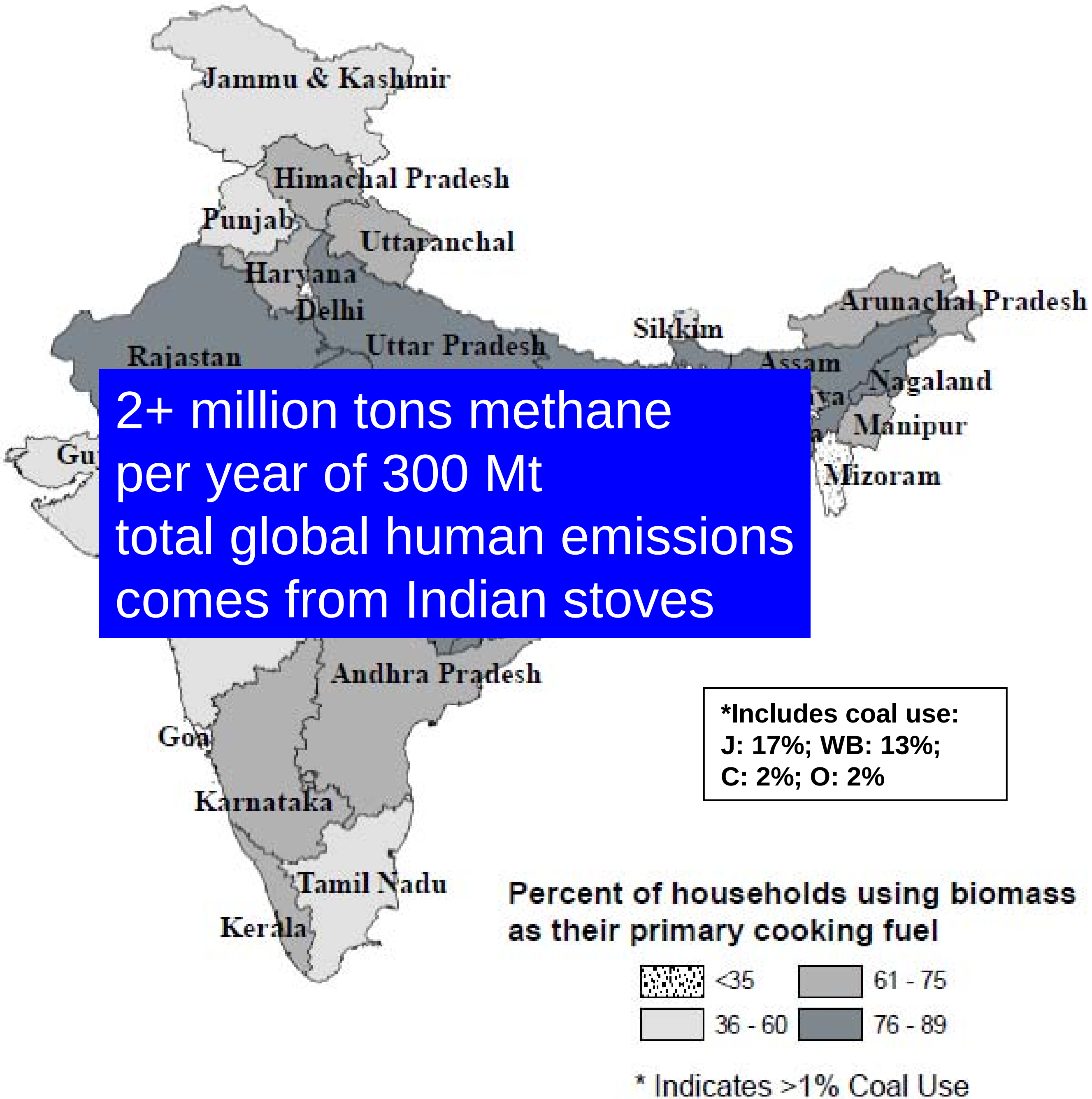
IPCC, 2007

Greenhouse warming commitment per meal for typical biomass-fired cookstove in China



Zhang, et al., 2000

India in 2005



2+ million tons methane
per year of 300 Mt
total global human emissions
comes from Indian stoves

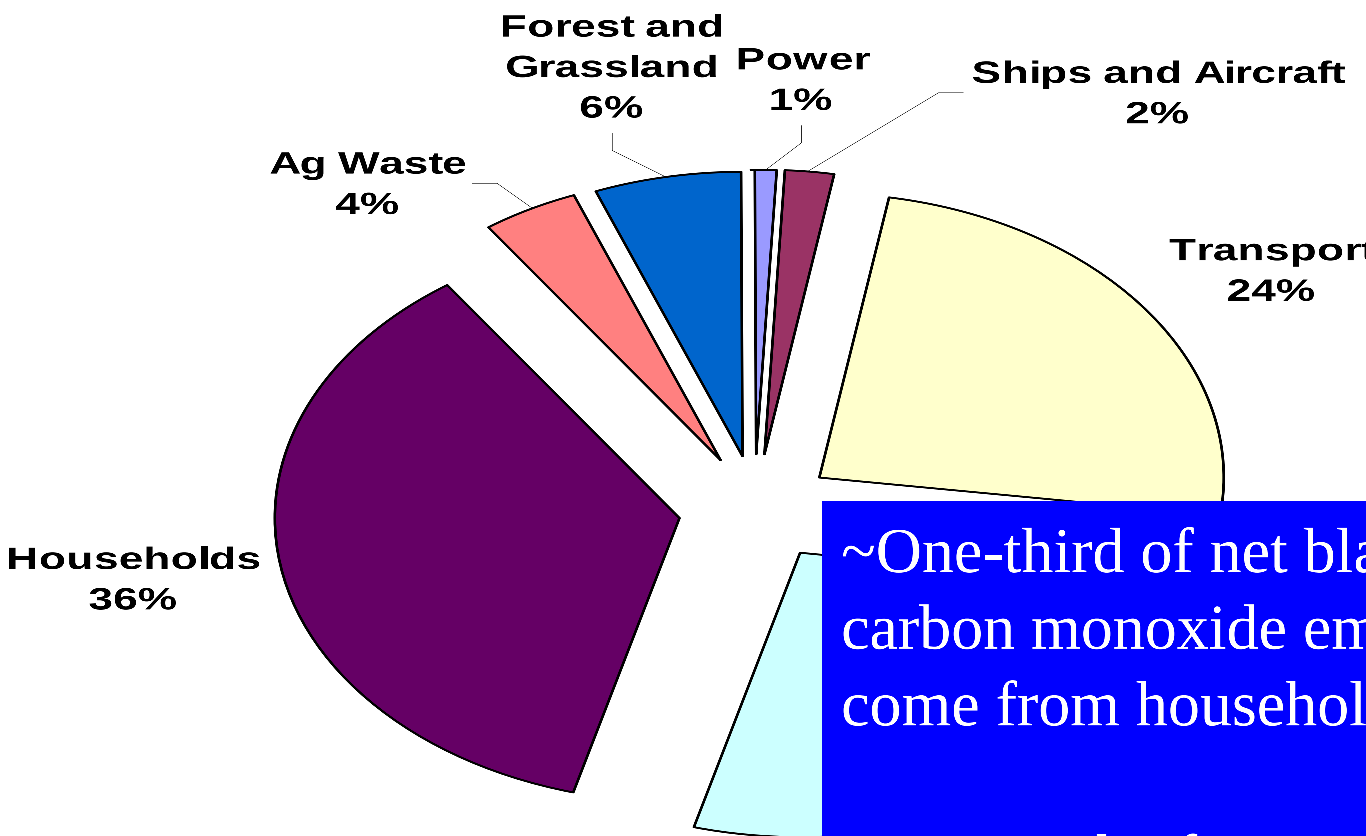
***Includes coal use:**
J: 17%; WB: 13%;
C: 2%; O: 2%

Venkataraman et al. 2010

Controllable Global Warming from Black Carbon Emissions

Net of OC, Forcings from IPCC, 2007: 0.25 W/m^2

Inventory from T Bond Database, V 7.1.1 Feb 2009

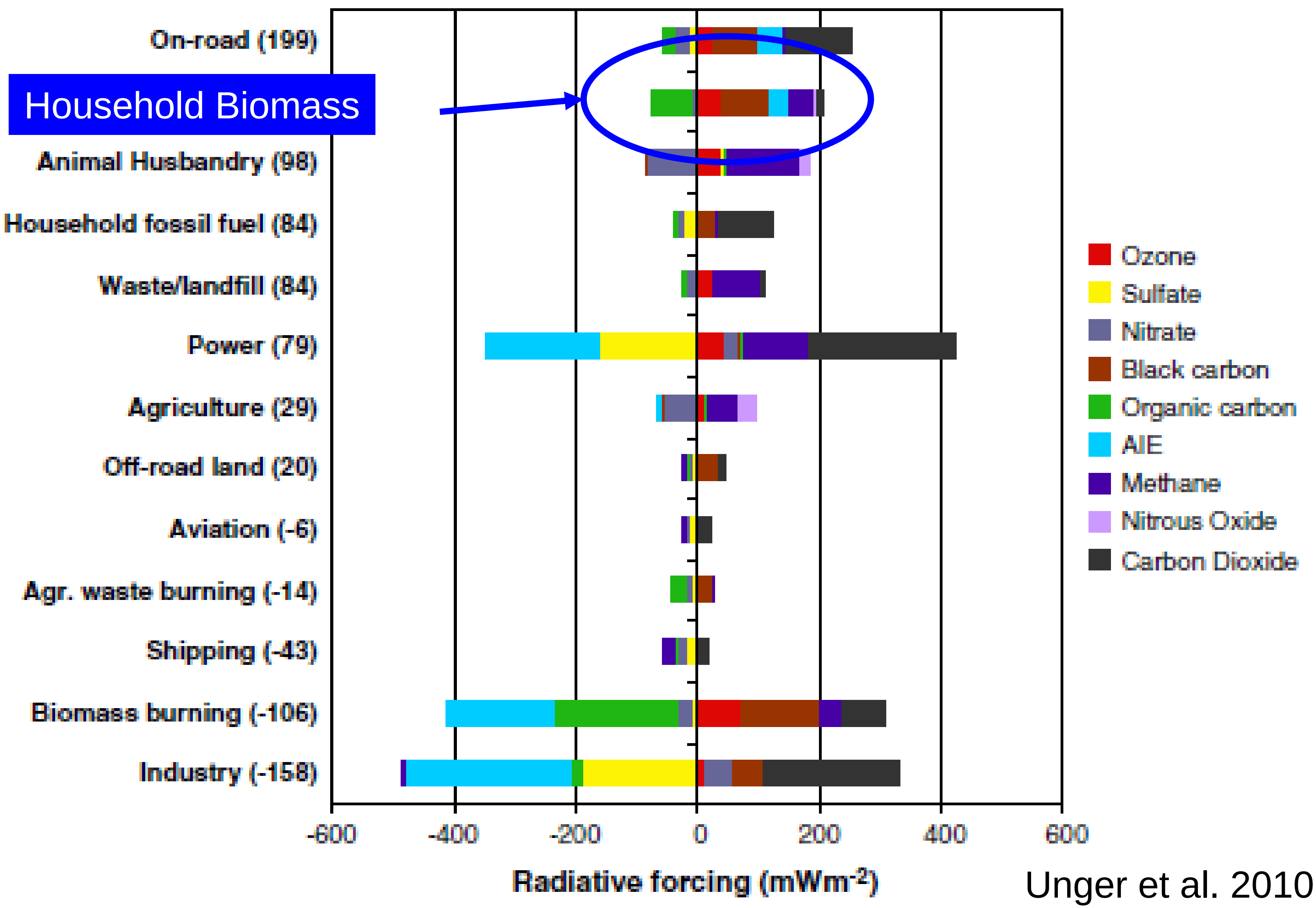


~One-third of net black carbon an
carbon monoxide emissions globa
come from household fuels

~One-sixth of ozone causing pollu

~One-twentieth of methane

Climate Warming in 2020 Under Present Trends

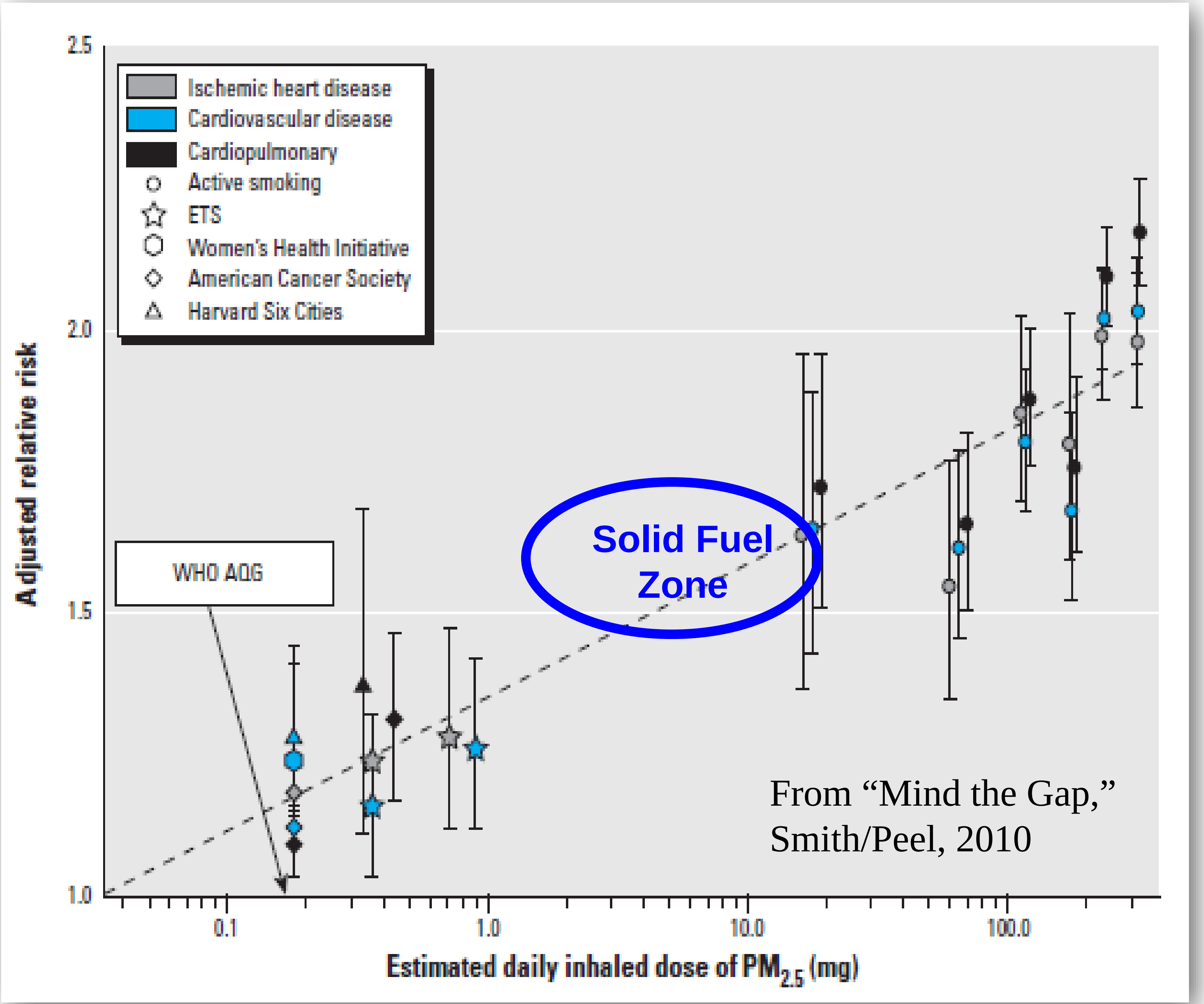


Unger et al. 2010

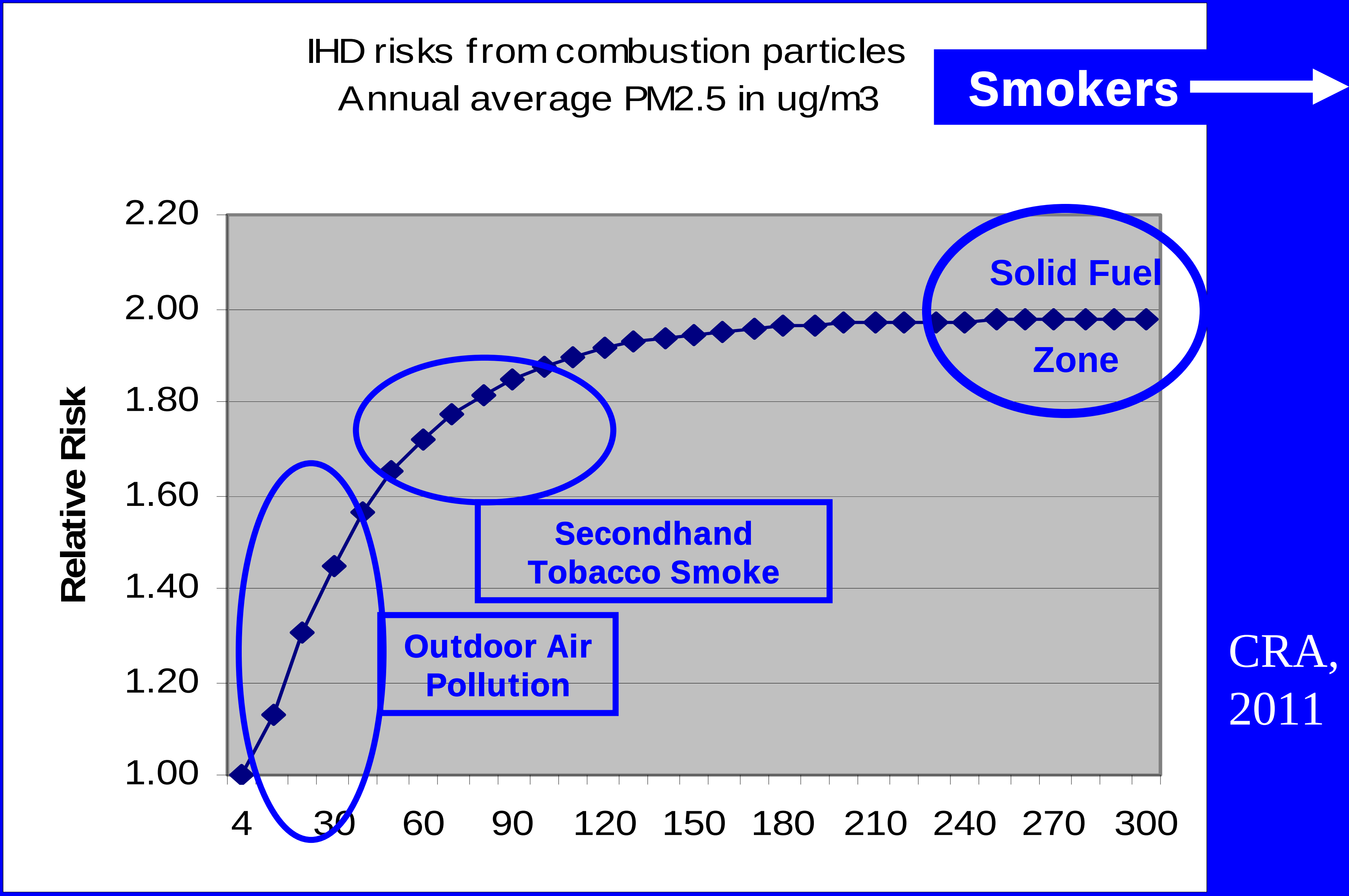
Household Fuels and Climate

- Climate impacts come from non-renewable wood, i.e., from net CO_2 emissions due to deforestation
- Poor combustion also leads to other emissions such as the relatively well-understood GHGs – methane and nitrous oxide – which are “Kyoto” GHGs
- In addition, a wide range of less well-understood short-lived GH-related emissions are emitted including
  - CO and black carbon – warming agents
  - Ozone precursors – warming But also cooling agents such as sulfates and organic carbon particles
- There are also indirect climate impacts of these pollutants including
  - Reducing carbon capture of forests by ozone damage
  - Darkening of snow/ice by black carbon

Heart Disease and Combustion Particle Doses

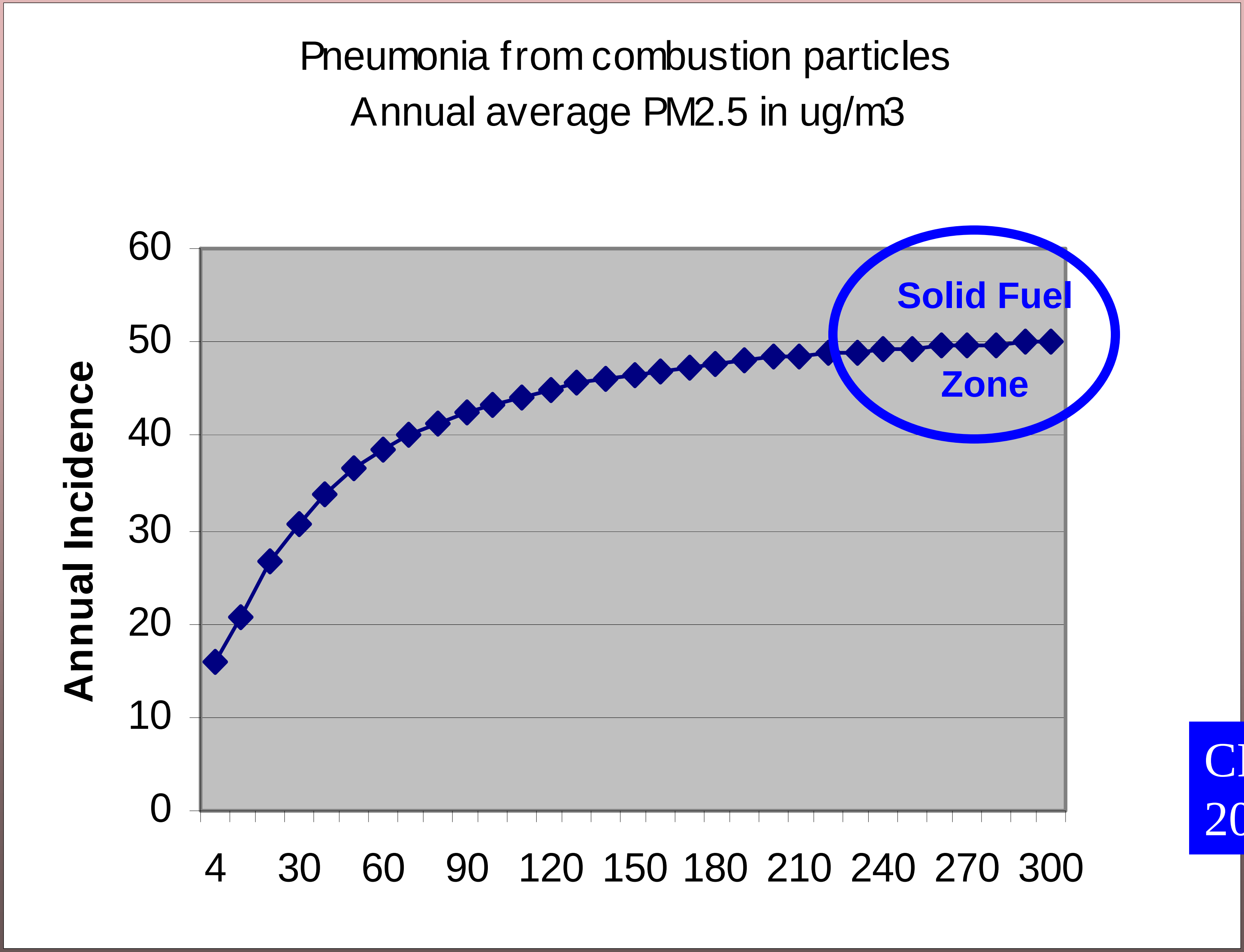


Generalized Exposure-Response: Outdoor Air, SHS, and Smoking



CRA, 2011

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



CRA, 2011

Why M&E?

You don't get what you expect,

but what you inspect

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 ehs.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 enviromental 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

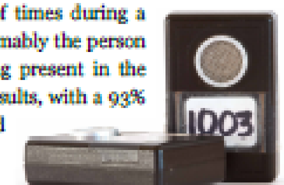
The ability to measure concentrations of small airborne particles is vital in understanding adverse health effects from combustion-derived air pollution. Available instrumentation to conduct such measurements is complex and expensive. Such devices are appropriate for developed countries and ambient air 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.

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.

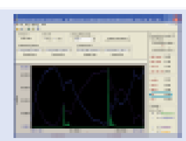
Time-Activity Monitoring System (TAMS) detects the presence or absence of individuals in an enclosed space. The system consists of one to five small ultrasound emitting devices worn on an individual's clothing. Each produces a distinct pattern that is emitted every few seconds. An ultrasound receiver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

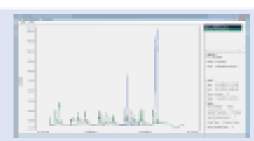
If the identifying signal pattern emitted from a particular locator is received a certain number of times during a minute, that locator, and presumably the person wearing it, is recorded as being present in the room. Field trials show good results, with a 93% accuracy rate as measured against direct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

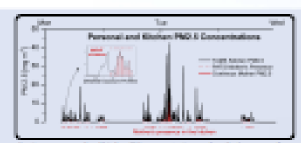


Device Software & Sample Output

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

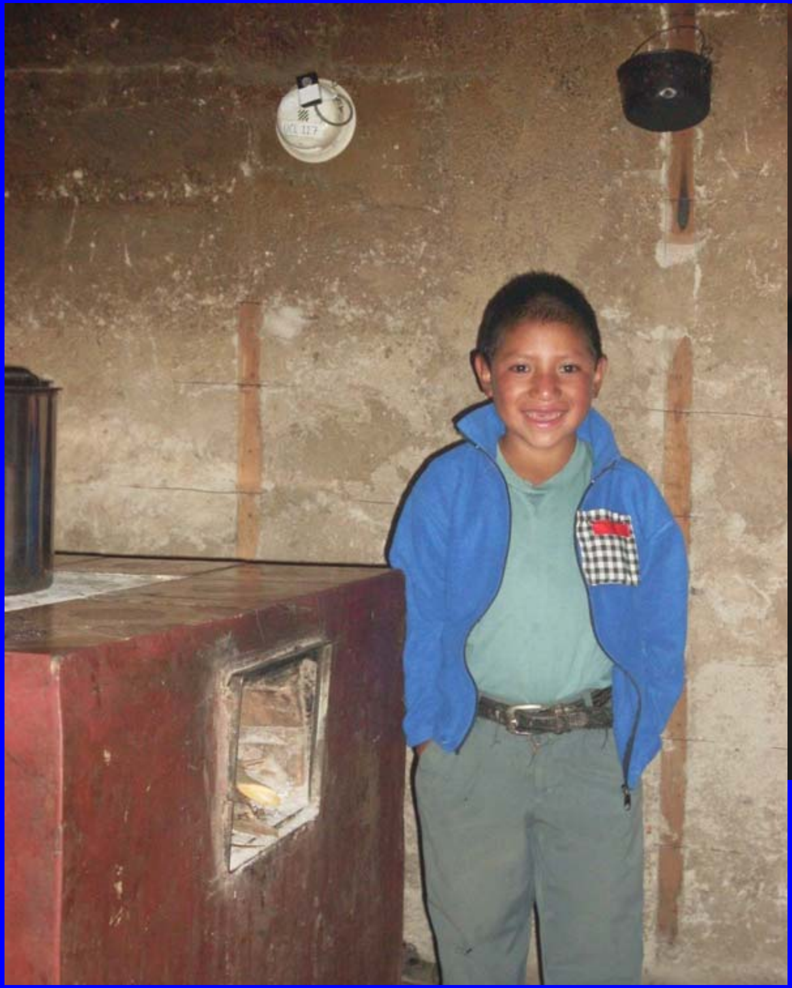






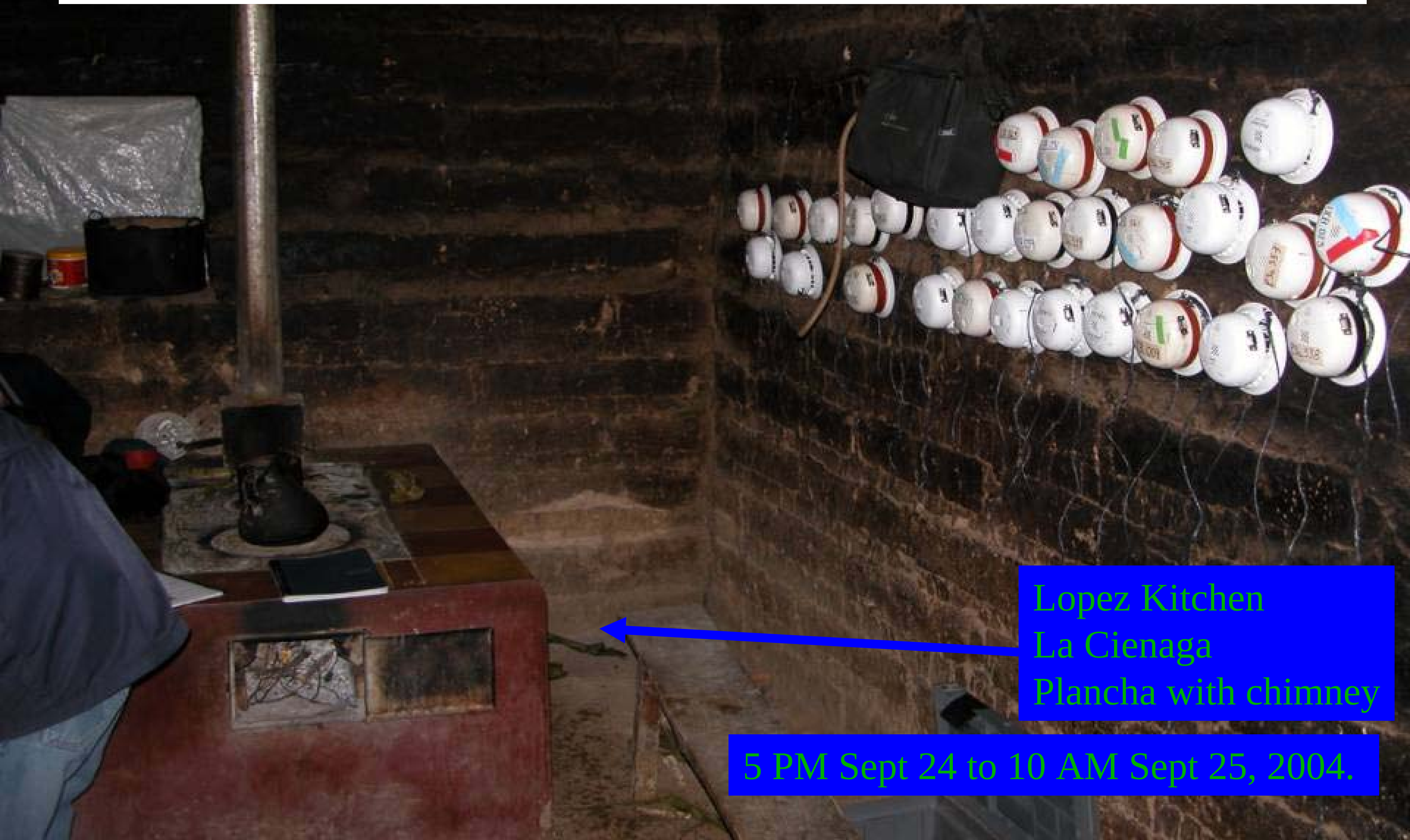
For more information, google "Kirk R Smith" • To acquire devices, visit berkeleyair.com

The Time-Activity Monitoring System: UCB-SUMS



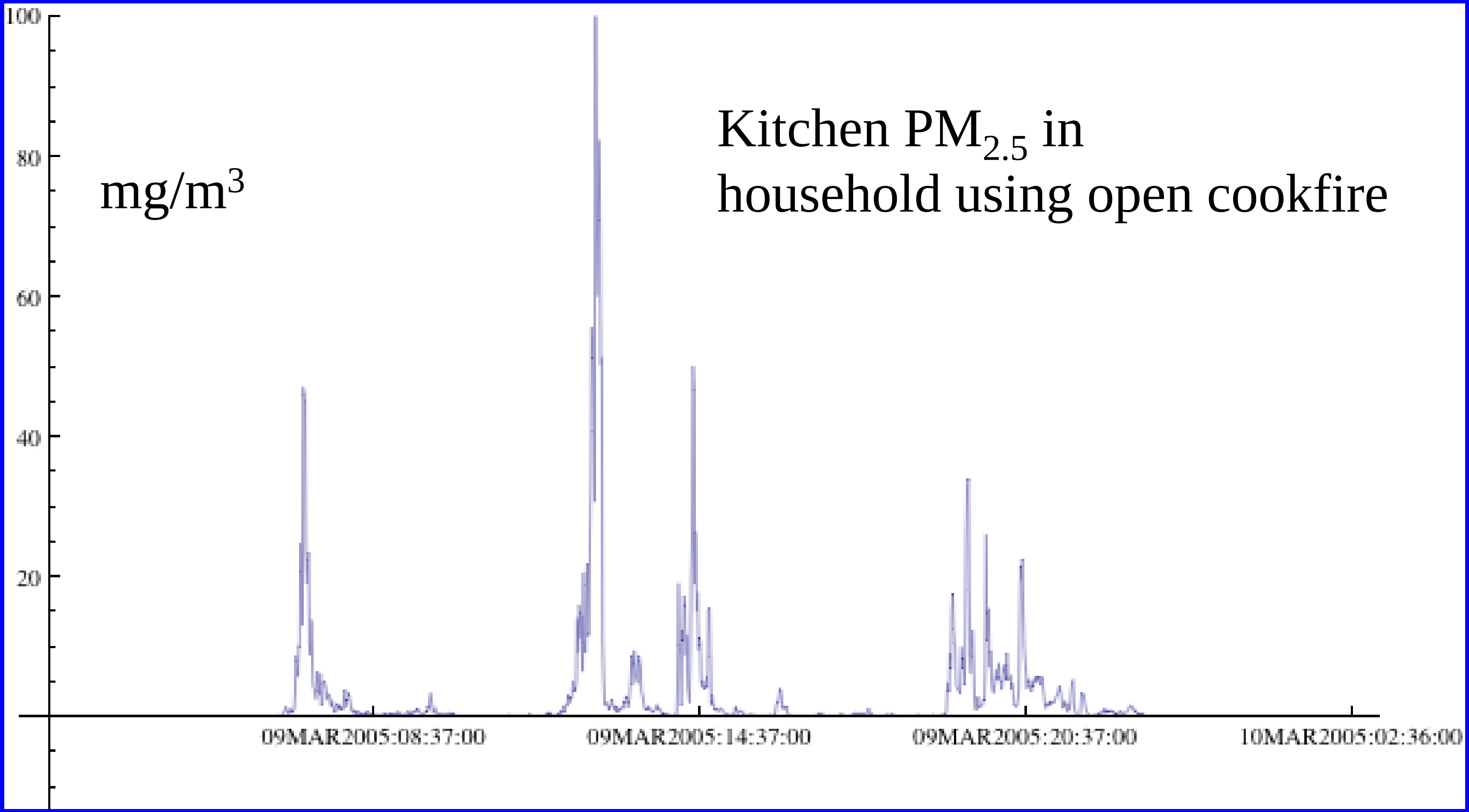
Inter-instrument Comparison: 30 UCB-PATS UCB Particle and Temperature Monitoring System

(custom PM monitor using smoke alarm technology)

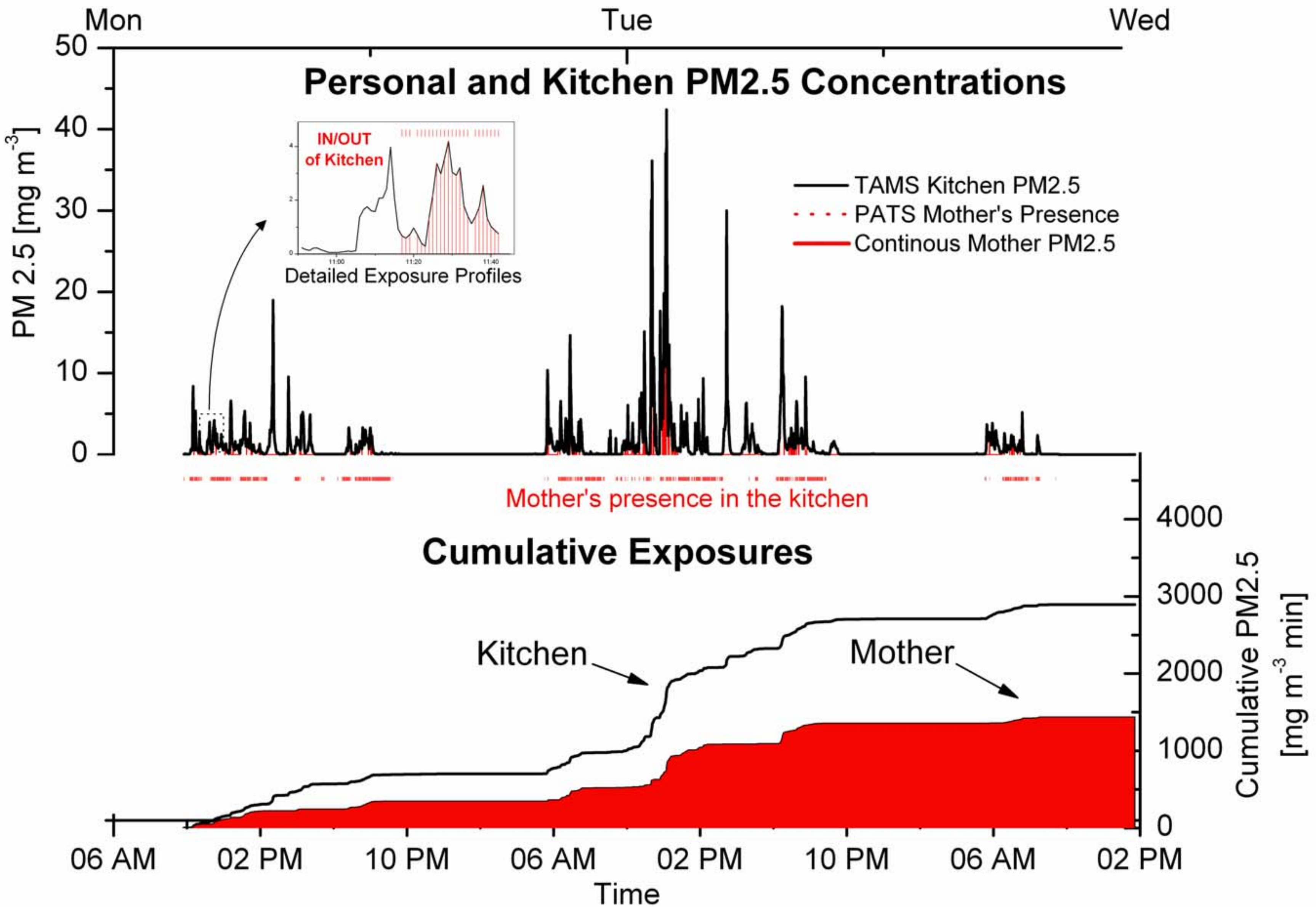


UCB Particle Monitor

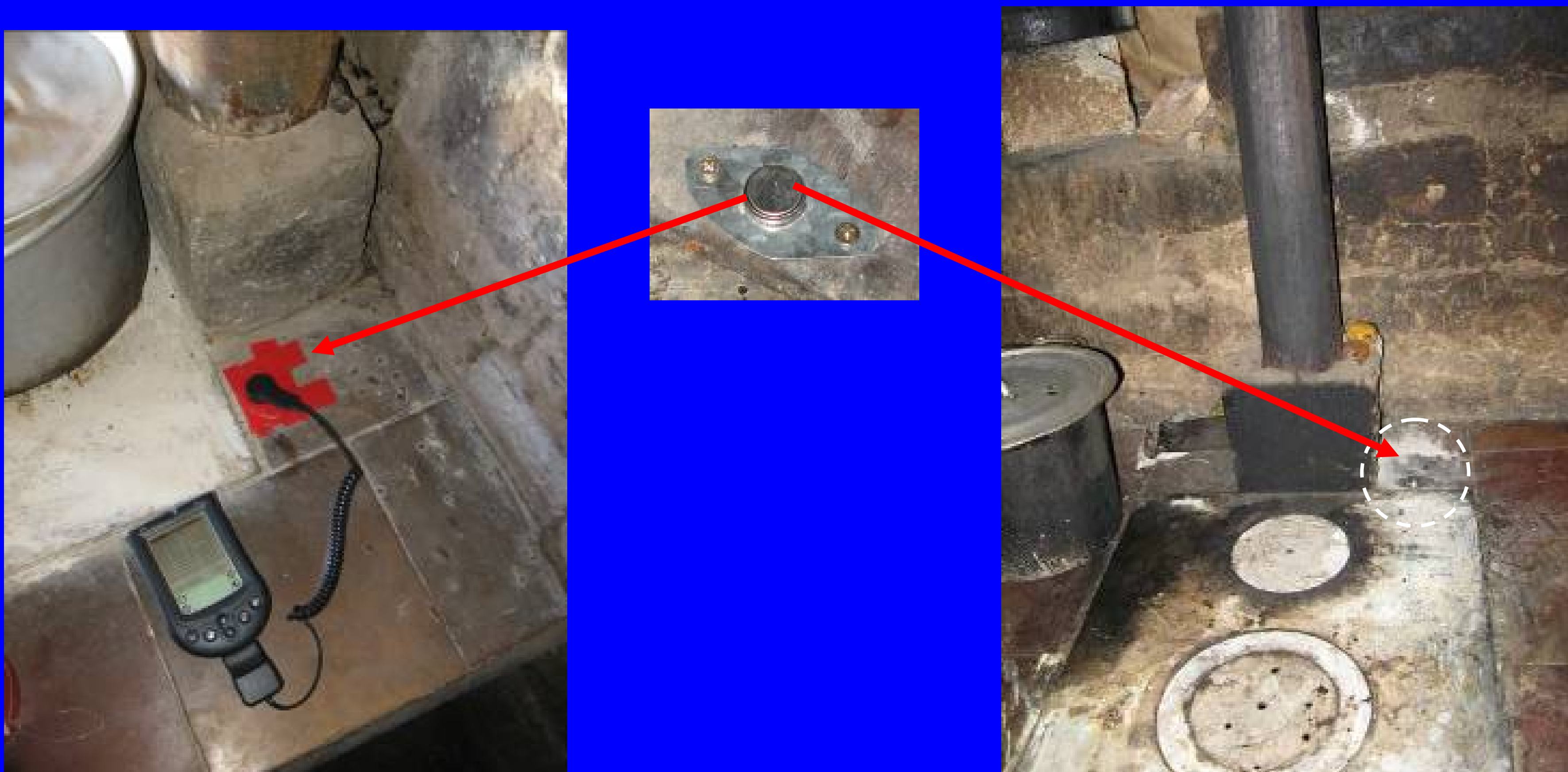
How many hours should we measure to obtain good estimate of the long-term mean?



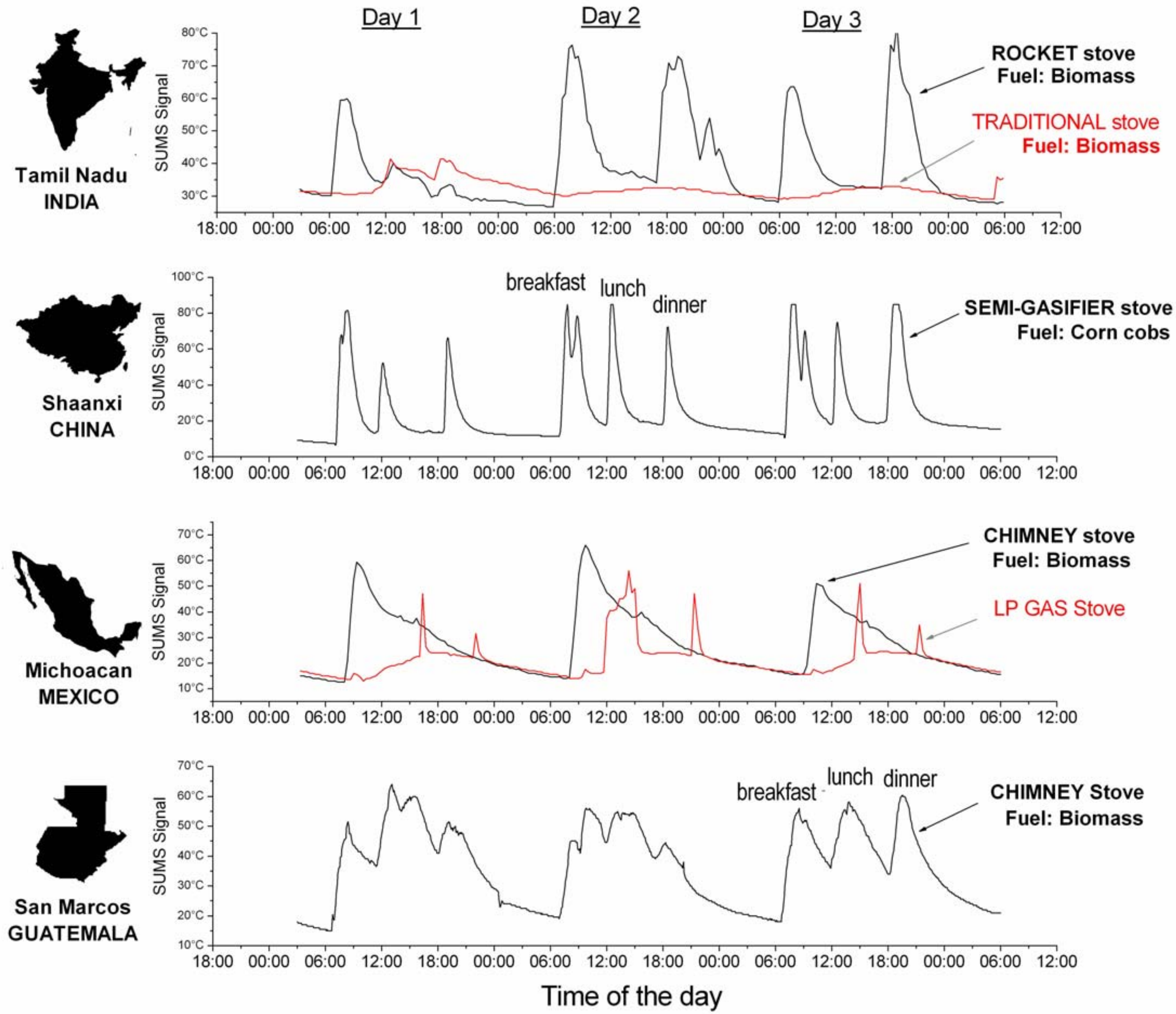
Estimating Mother's Personal Kitchen PM2.5 Exposure Pattern by Combining Time-Activity Data (TAMS) with Continuous PM2.5 Kitchen Area Measurements (PATS)



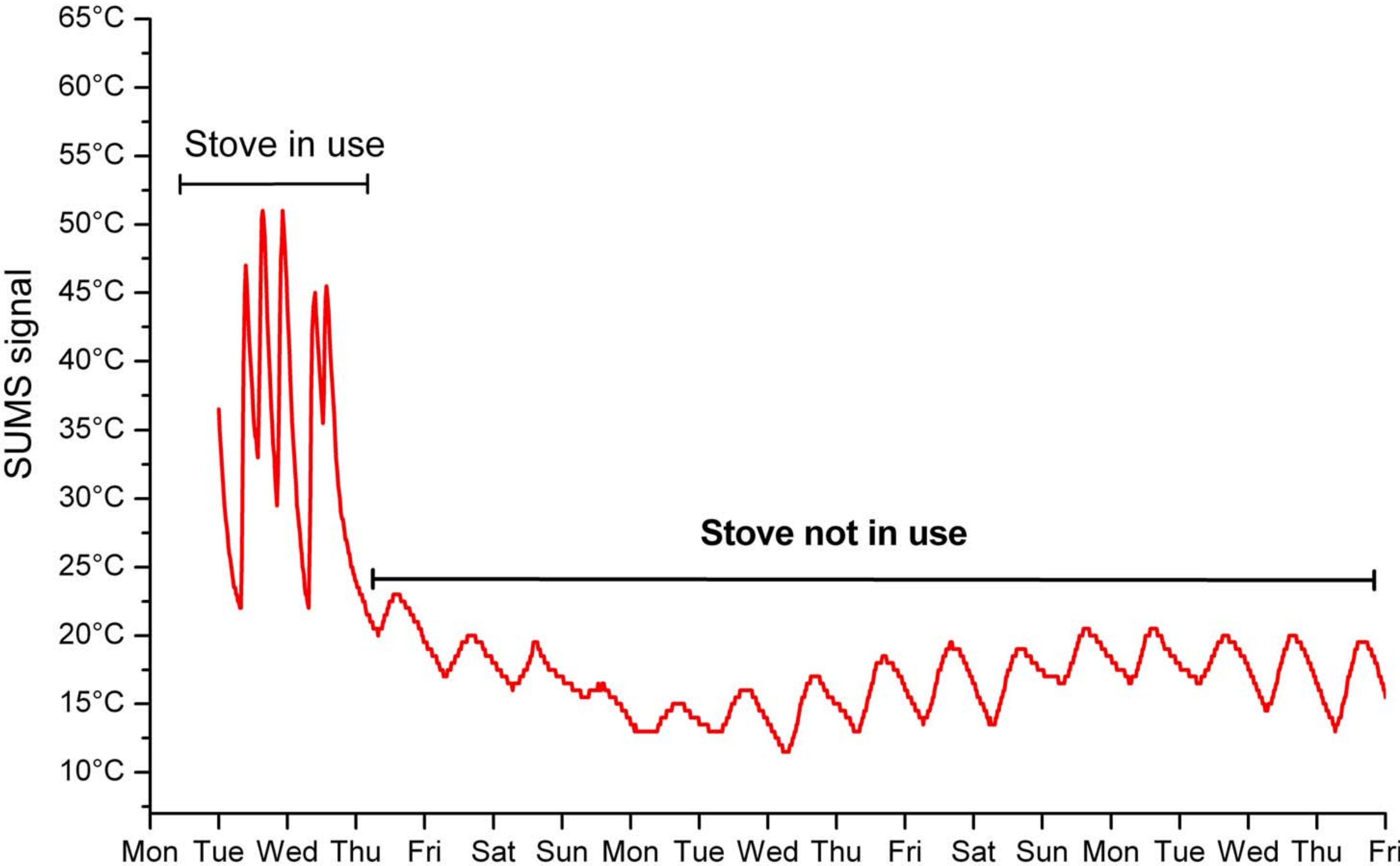
The Stove Use Monitoring System: UCB-SUMS



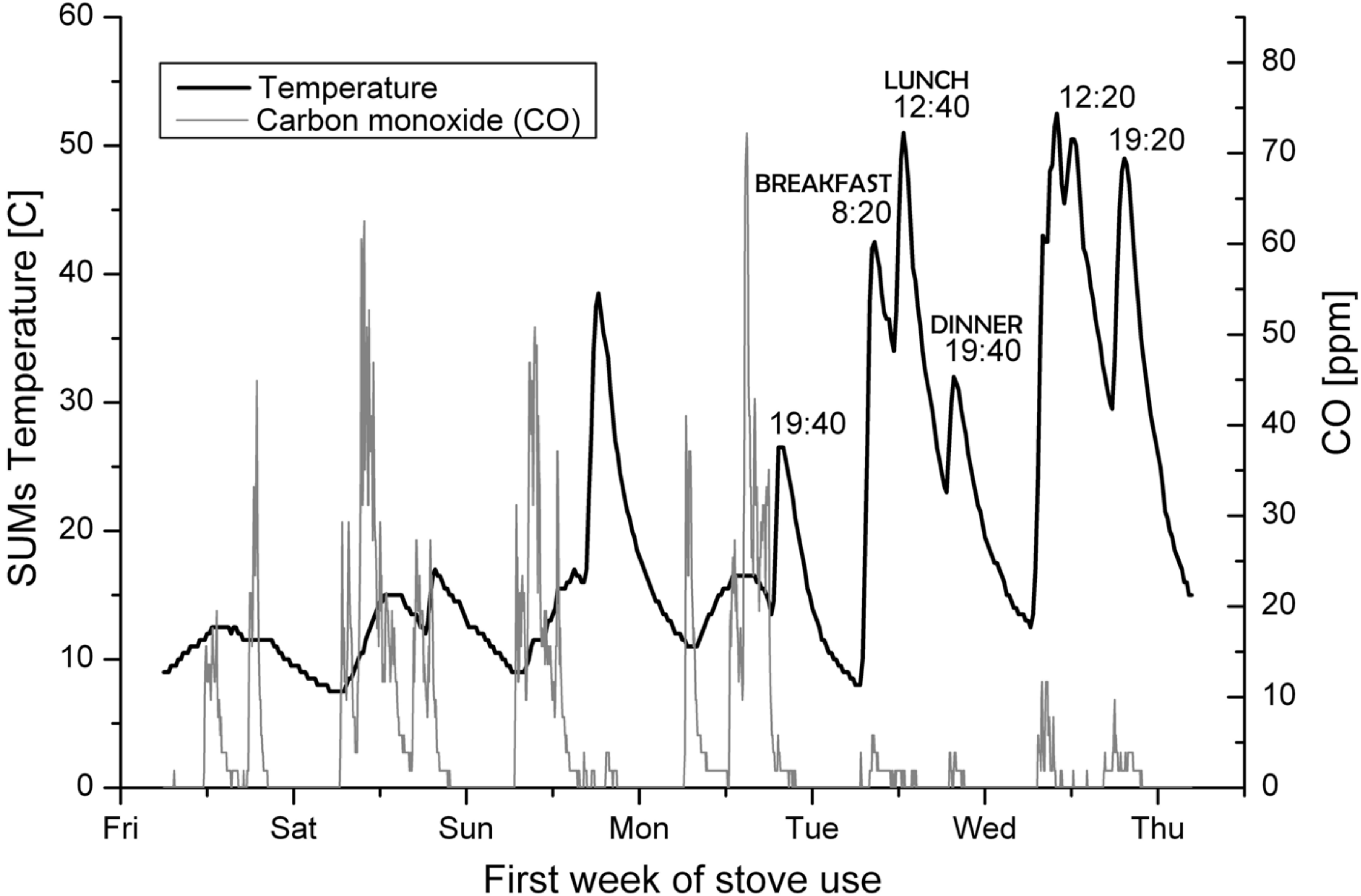
Patterns of Stove Use from Around the World
Captured with the UCB-SUMS



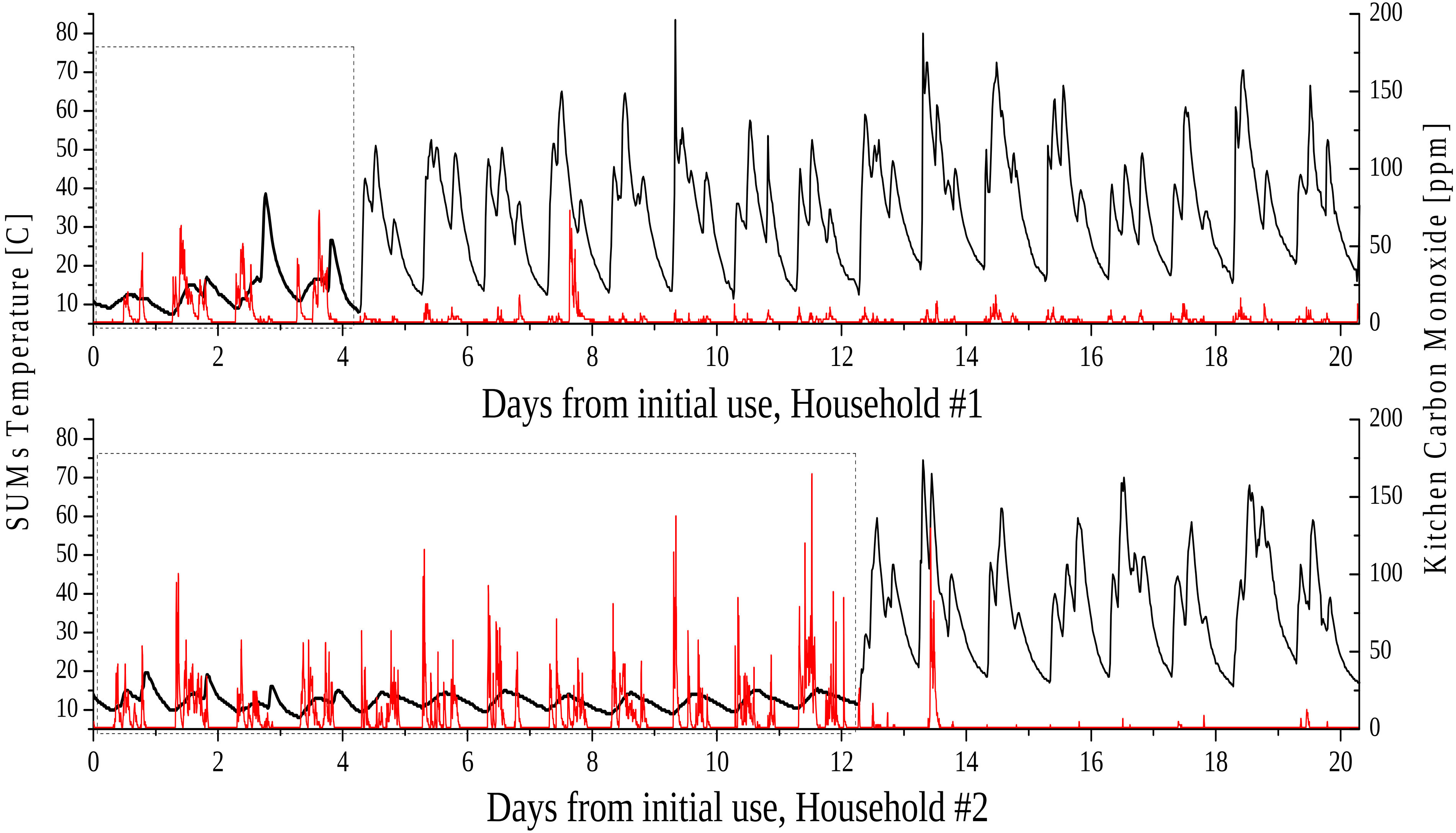
Objective Monitoring with the UCB-SUMS System



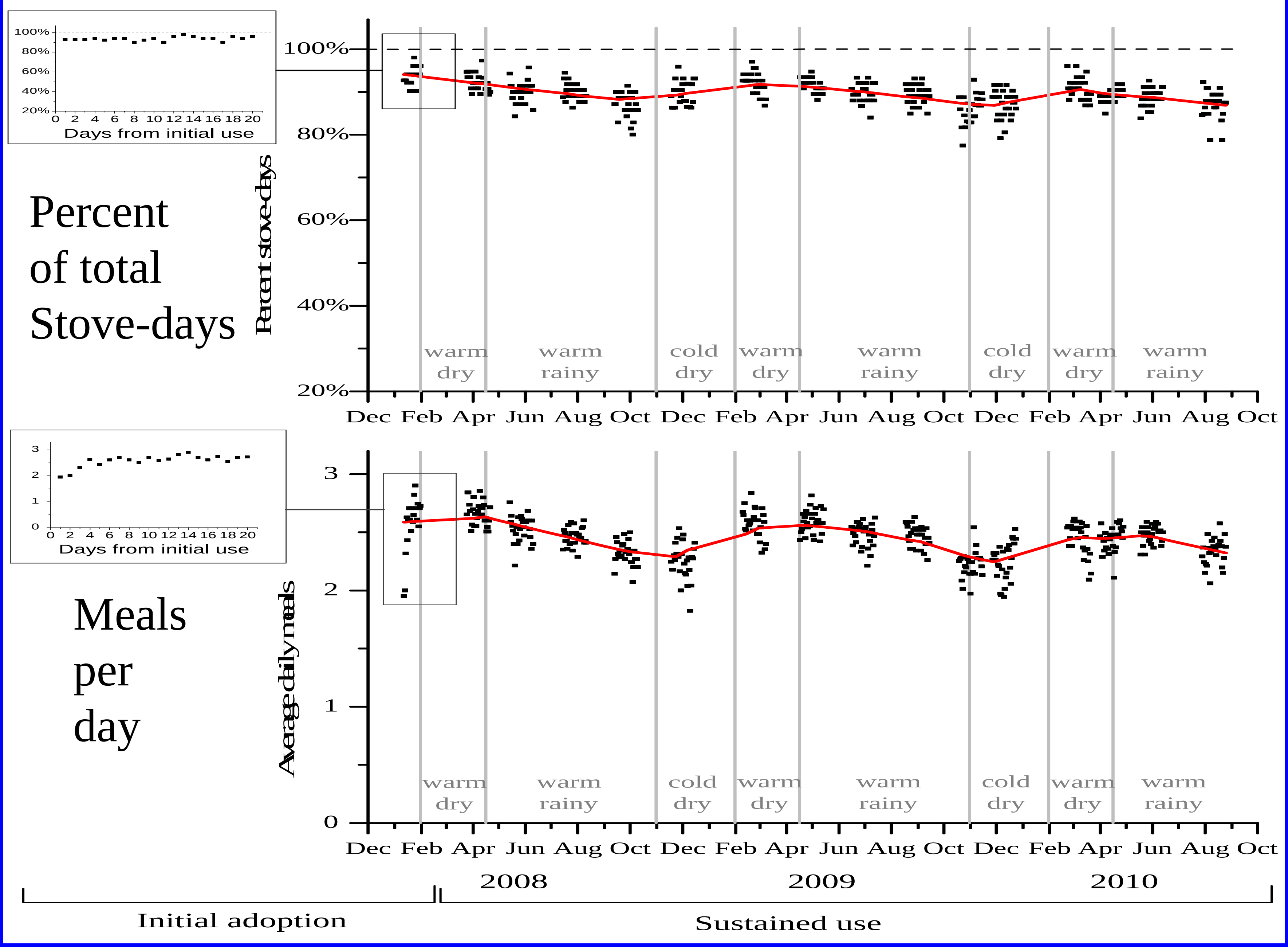
Transition from open fire to a chimney stove



Stove Use Monitors (SUMs) in Action



Ruiz et al., submitted



Ruiz et al., submitted

Wireless Stove Use Monitors Being Field Tested in Mexico This Month – India next year

Principles by Which to Move Forward

- “Get rid of incomplete combustion” – bad for health, climate, ecosystems, agriculture and resource efficiency
- “You don’t get what you expect, but what you inspect” -- need to monitor in the field for both technical performance and usage
- “Not all stoves are equally bad” -- need to target vulnerable populations

Stoves, a few principles.

- “Improved” has not meant clean. Need to combust cleanly, not just have good fuel efficiency or a chimney
  - 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 will not bring health/climate benefits

Many thanks

Publications and presentations available at my website: http://ehs.sph.berkeley.edu/krsmith/

Or just Google “Kirk R. Smith”