Co-benefit Thinking to Link Atmospheric Chemistry Research to Pollution-Reduction Policy

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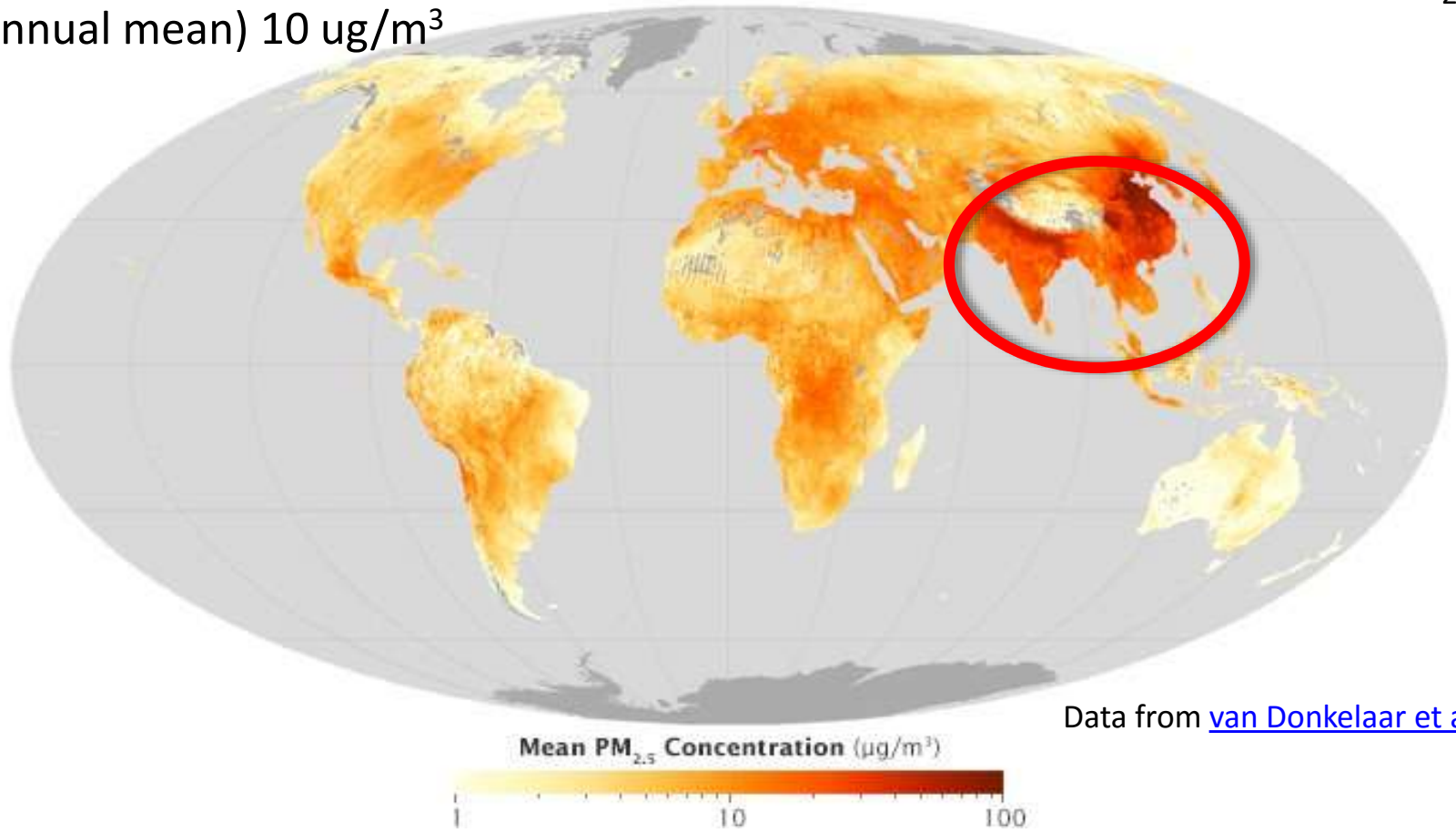
Fine particulate matter ($PM_{2.5}$) concentration for 2010-2012 without dust and sea salt included

$PM_{2.5}$: Particulate matter (or aerosols), aerodynamic diameter is less than 2.5 micrometer

- a classified human carcinogen, a major environmental health problem
- World Health Organization (WHO) recommended guideline for $PM_{2.5}$: (annual mean) 10 ug/m^3



Data from van Donkelaar et al.(2015)

Climate Change makes air pollution worse

air pollution contributed to heart disease, stroke, lung cancer, bronchitis, emphysema and acute infections

[Brauer et al., 2016; The Guardian, Feb. 12, 2016]

Air pollution: a dark cloud of filth poisons the world's cities

The number of annual deaths caused by pollution around the world is now greater than malaria and HIV combined, according to a recent study, with scientists warning that fatalities could reach 6 million a year by 2050

Heavy smog in the Lujiazui financial district of Shanghai. Photograph: Corbis

http://www.theguardian.com/global-development/2016/jan/16/winter-smog-hits-worlds-cities-air-pollution-soars

Scientists: air pollution led to more than 5.5 million premature deaths in 2013

More than half of the deaths were in India and China, and researchers compared air pollution problem to the conditions under centuries of industrial revolution

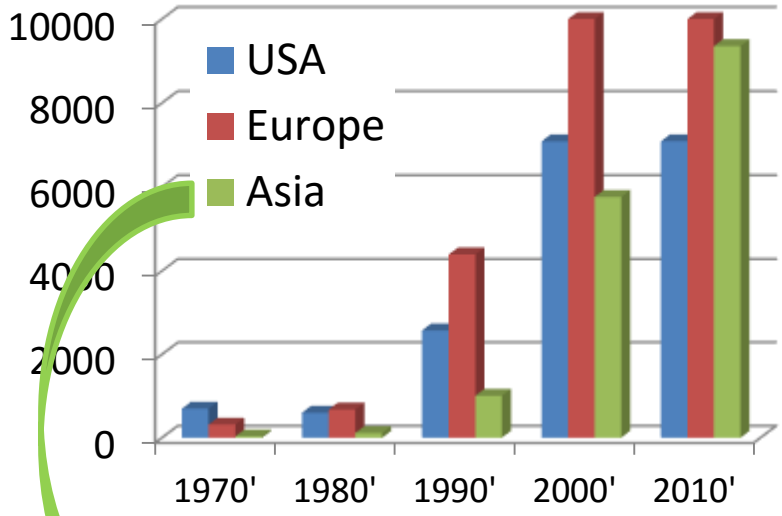
According to scientists, conditions caused by air pollution killed 1.6 million people in China and 1.4 million people in India in 2013. Photograph: Xiaolu Chu/Getty Images

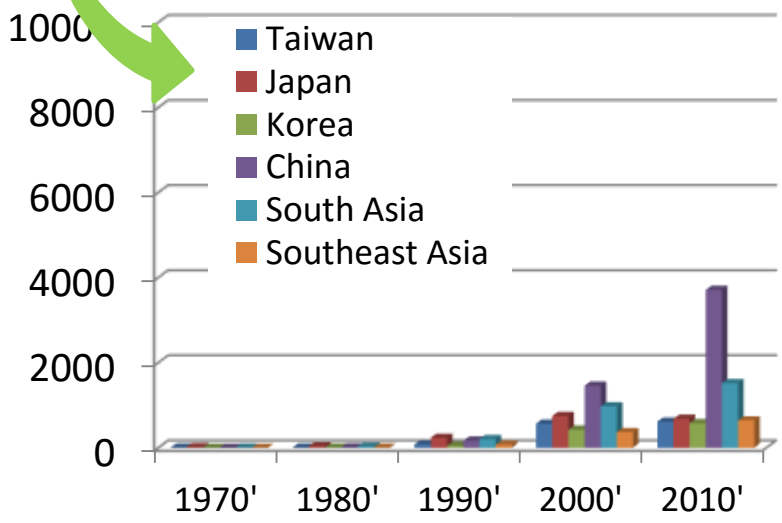
According to scientists, conditions caused by air pollution killed 1.6 million people in China and 1.4 million people in India in 2013. Photograph: Xiaolu Chu/Getty Images

http://www.theguardian.com/environment/2016/feb/12/air-pollution-deaths-india-china

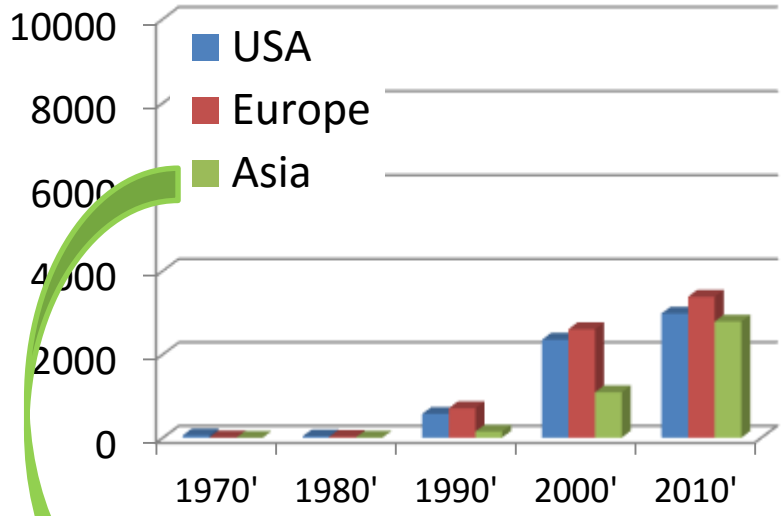
Numbers of Publication

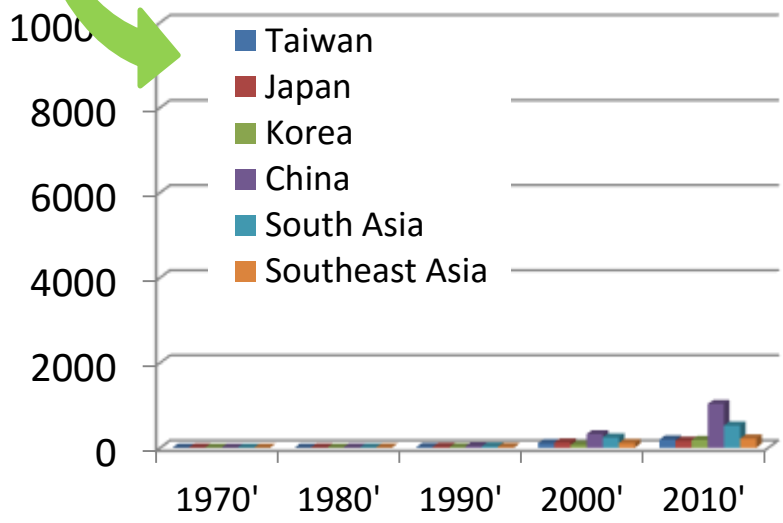
Keywords: Air Pollution





Keywords: Air Pollution and Health





Co-benefits

nature climate change

ARTICLES

PUBLISHED ONLINE: 24 AUGUST 2014 | DOI: 10.1038/NCLIMATE2342

A systems approach to evaluating the air quality co-benefits of US carbon policies

Tammy M. Thompson[1*†], Sebastian Rausch[1†], Rebecca K. Saari[2] and Noelle E. Se

Because human activities emit greenhouse gases (GHGs) and conventional air pollutants from
designed to reduce GHGs can have co-benefits for air quality that may offset some or all of the

nature climate change

LETTERS

PUBLISHED ONLINE: 22 SEPTEMBER 2013 | DOI: 10.1038/NCLIMATE2009

Co-benefits of mitigating global greenhouse gas emissions for future air quality and human health

J. Jason West[1]*, Steven J. Smith[2], Raquel A. Silva[1], Vaishali Naik[3], Yuqiang Zhang[1],
delman[1], Meridith M. Fry[1], Susan Anenberg[4], Larry W. Horowitz[5]
ancois Lamarque[6]

uce greenhouse gas (GHG) emissions often
ted air pollutants, bringing co-benefits for air
Global GHG emission reductions are modelled in the Representative Concentration Pathway 4.5 (RCP4.5) scenario[18]

Environ. Res. Lett. 10 (2015) 085006 doi:10.1088/1748-9326/10/8/085006

Environmental Research Letters

LETTER

Air pollution co-benefits of low carbon policies in road transport: a sub-national assessment for India

Shivika Mittal[1], Tatsuya Hanaoka[1], Priyadarshi R Shukla[2] and Toshihiko Masui[1]

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[2] Indian Institute of Management, Ahmedabad, India

E-mail: mittal.shivika@nies.go.jp

Keywords: low carbon, air quality, road passenger transport, co-benefits, AIM/Enduse

Applied Energy 144 (2015) 165–174

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Pursuing air pollutant co-benefits of CO_2 mitigation in China: A provincial leveled analysis

Huijuan Dong[a,*], Hancheng Dai[a], Liang Dong[b], Tsuyoshi Fujita[a,*], Yong Geng[b,*], Zbigniew Klimont[c], Tsuyoshi Inoue[d], Shintaro Bunya[d], Minoru Fujii[d], Toshihiko Masui[a]

[a] National Institute for Environmental Studies, 16-2 Onogawa, Tsukuba, Ibaraki 305-8506, Japan
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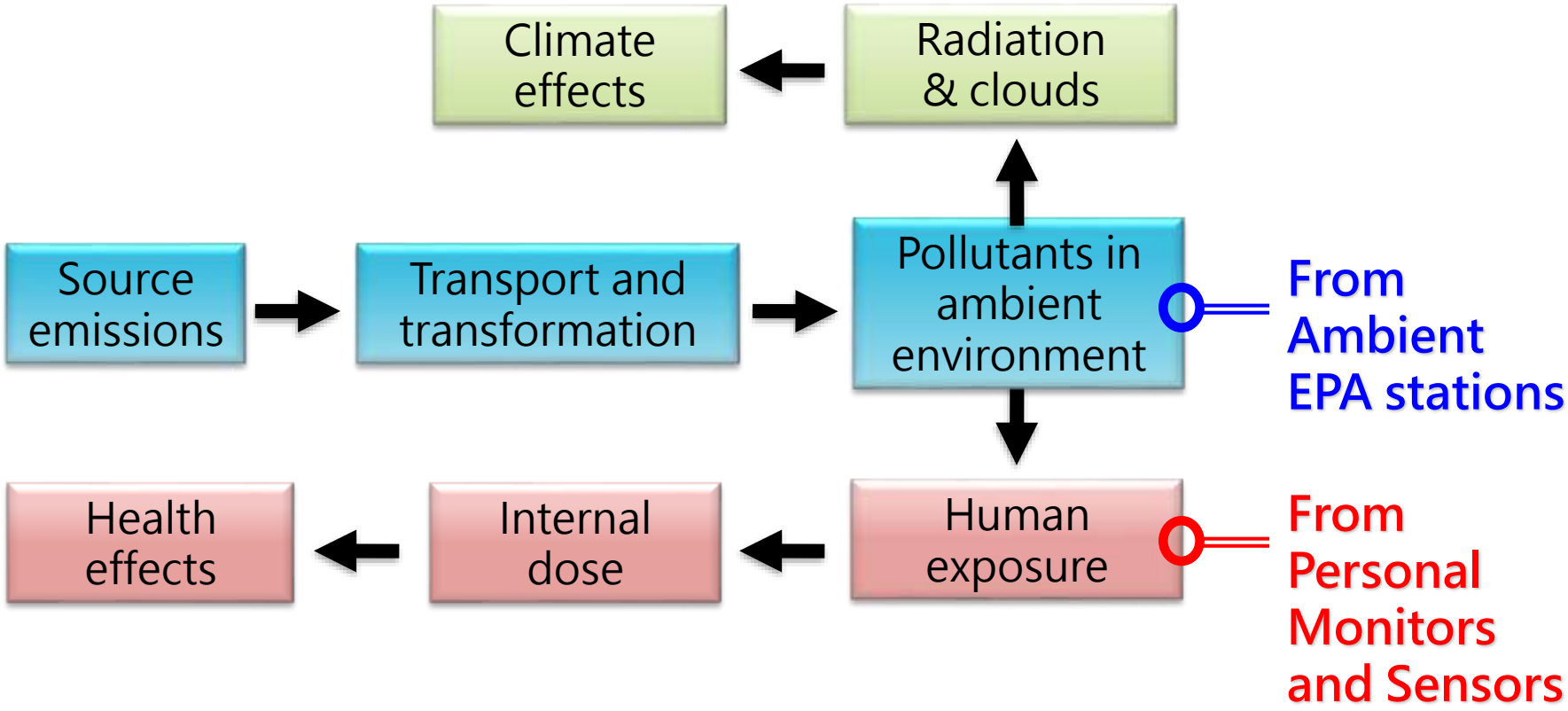
[d] Mitsubishi Research Institute Inc., 2-10-3, Nagatacho, Chiyoda-Ku, Tokyo 100-8141, Japan

Co-benefits

Emphases in futureearth research for global sustainability	Co-Benefit Thinking
• Fundamental to user-inspired solution-oriented earth system research	• Scientists and society
• Cross-disciplinary collaboration	• Among different disciplines
• International collaboration	• Among countries
• Stakeholder engagement	• Among scientists and different stakeholders

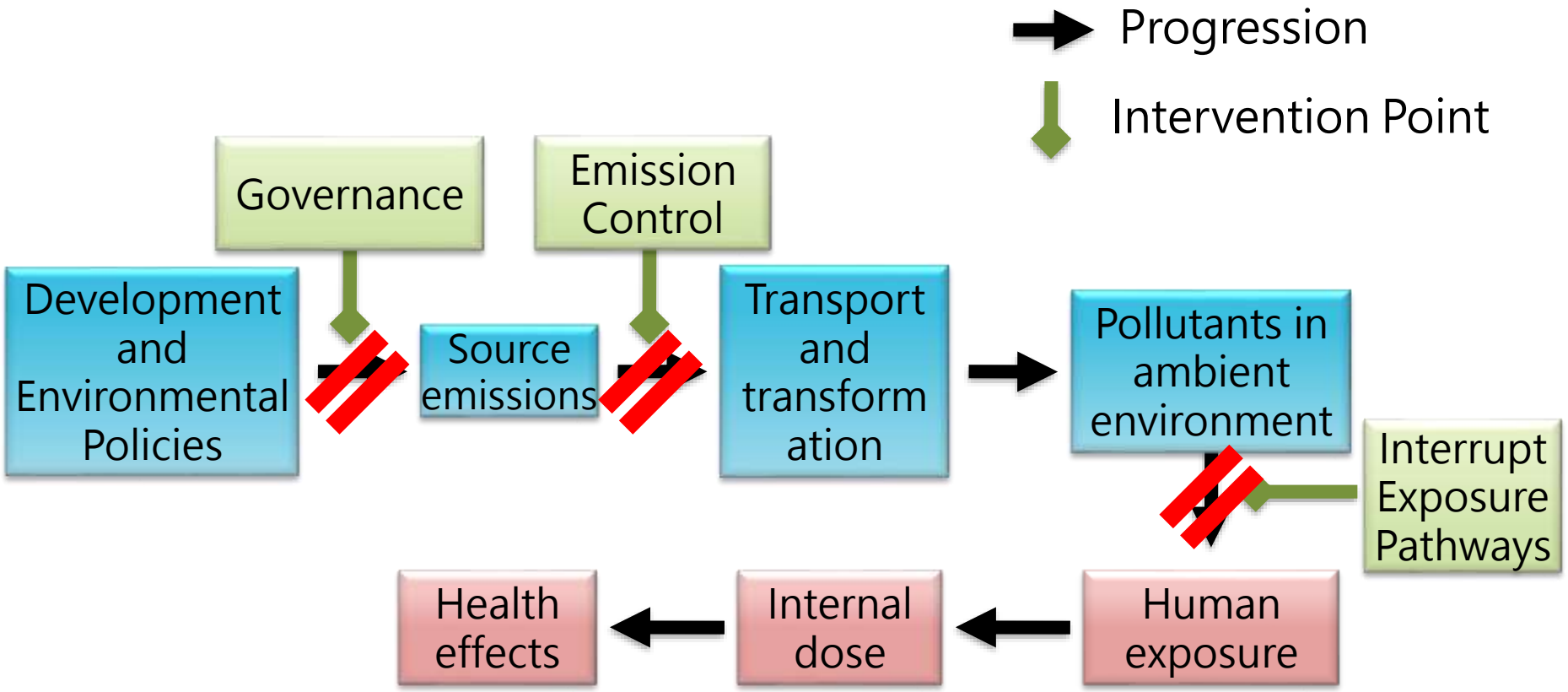
Progression of Particles from Emissions to Health/Climate Effects



Why is " $PM_{2.5}$ exposure concentration" important?

- More accurate estimates for exposure, more accurate estimates for damage coefficients of exposure-health relationships
  - 17% increase in all-cause mortality when more spatially resolved exposure estimates were used for a LA subgroup of the American Cancer Society population (Jerrett et al., 2005) compared with 6% increase in an earlier study for 10ug/m^3 increase in $PM_{2.5}$ for ACS population (Pope III et al., 2002)
- People are directly exposed to freshly emitted aerosols with different physio-chemical properties compared to ambient aerosols
- Peak exposures, which may induce asthmatic attacks and other health effects, are much higher than ambient levels

Potential intervention points to reduce health impacts of air pollution



Questions asked ourselves

- What are the controllable factors that our study can identify?
- Can we provide policy recommendations that can reduce the impacts of the identified controllable factors and actually reduce air pollutant levels
- What policy recommendations can we make based on our study results that are different compared to previous policies?

Scientific Challenges Could Be Tackled by Atmospheric Chemists

- **Source characterization** of freshly emitted particles from community sources and personal activities
  - ex. Critical physio-chemical properties and major toxic constituents of $PM_{2.5}$ which are responsible for major health effects
- **Source apportionment** of air pollutants in the ambient air and human exposure
  - ex. Analytical methods for organic molecular markers
- **Fundamental mechanisms** which facilitate policy makers to prioritize pollution control
  - ex. Mechanisms lead to development of inexpensive, light-weight, easy-to-use sensing devices
- **Chemical processes** which links to policy responses
  - ex. Chemical transformation mechanisms of particles after encountering with building materials
  - ex. Better street canyon models with chemical transformation process as a tool for spatial distribution of $PM_{2.5}$ in community scale
- **Cross-scale studies** link local, regional and global scales of atmospheric chemistry gaps

Regional Aspect: Community Air-Pollutant Sources in Asian Cities

$PM_{2.5}$ (WHO classified as a human carcinogen)

VOCs PAHs

NO_2 SO_2 many others

Asian style restaurant

Traffic

Temple

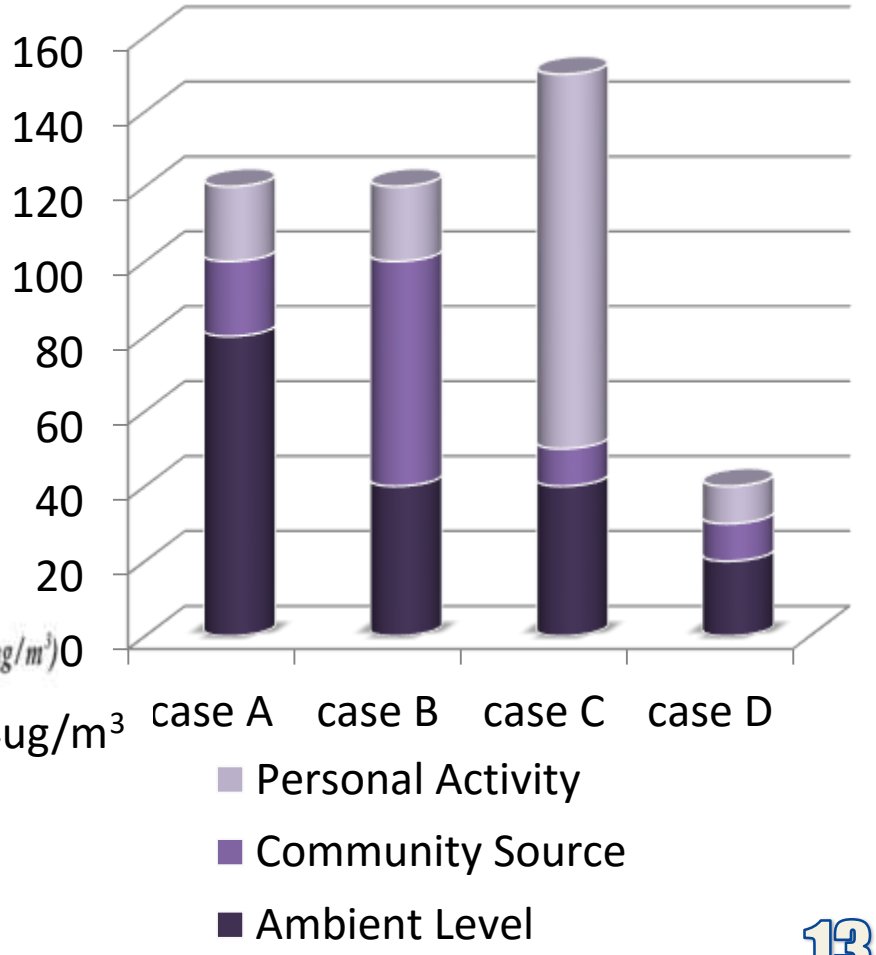
Night market

Hair salon

Car salon

Spatial Variability of $PM_{2.5}$ levels within a Taiwanese community

Exposure Level =**Ambient** level
+ **Community source** contribution
+ **Personal activity** contribution



[Candice LUNG, 2014]

Community Sources in Asia

Different Vehicles in Asia
(Cambodia, Sri Lanka, the Philippines)

Street Vendors in Asia
(China, Sri Lanka, Thailand)

Other sources: rice-straw burning, garbage open-burning, etc.

light-weight personal **PM2.5 Sampler**

PEM
- Personal Environmental Monitors
- SKC 761-203
- 37 mm Teflon filter

Elutriator
- Avoid wind interfering
- Carbon-filled Teflon surface to prevent static effect

Pump
- Portable with battery
- Flow rate: 4 L/min

- Subjects wear this sampling package for 24-hour to assess daily exposure
- 2-kg weight with low-level noise and vibration
- Need micro-balance with readability of 1 ug

Scientific work and study designs for **Incense-burning and Worshippers' Exposure**

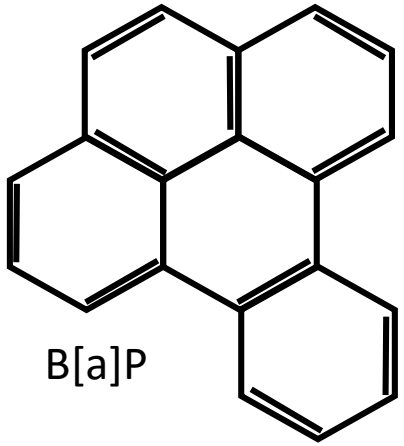
(started since 1999)

Controllable Factors!

Focus	Setting	Exposure factors
Emission Factors	Laboratory	Incense materials, combustion condition
Daily worshipping	Household environments	Closed vs. ventilated conditions; distance from censers; during-burning vs. after-burning
Monthly worshipping	temples	No. of incense used; no. of censers; No. of incense left in censers; dates of visit; etc
Annual worshipping	Ta-chia Ma-tzu Goddness Parade	Before parade vs. during parade; Time stayed in temples; riding motorcycles vs. driving cars

Worshippers' Exposure to $PM_{2.5}$ and Polycyclic Aromatic Hydrocarbons (PAHs)

- Incense-burning:
  - a long-lasting Chinese traditional to pay respect to ancestors
  - a ceremonial practices in Buddhism and Taoism; 60% of Taiwanese are either Buddhism or Taoism [Taiwan IOSH, 2000]
  - producing $PM_{2.5}$ and particulate PAHs
- PAHs
  - 16 PAHs: USEPA Priority Pollutants
  - Probable carcinogens
  - most toxic one: Benzo[a]pyrene
  - GC-MS and LC-MS/MS for analysis

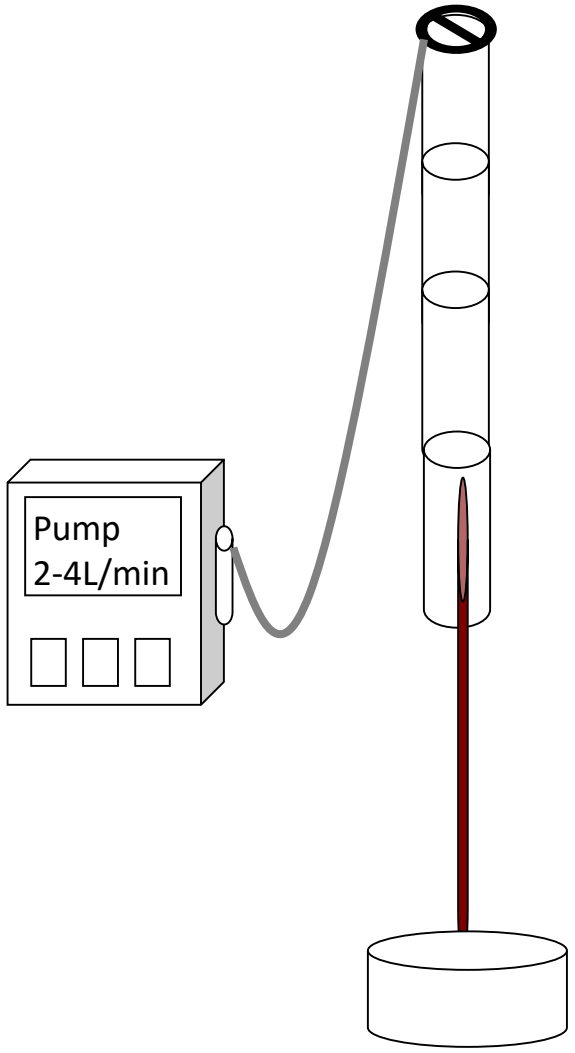

B[a]P

[Lung and Liu, 2011, **Analytical Chemistry,** 83(12):4955-4961]

Emission Factors of Incense-burning

[**Lung** & Hu, Chemosphere, 50, 673-679, 2003]

- Objectives: assessing emission factors of $PM_{2.5}$ and PAHs in the lab
- $PM_{2.5}$
  - Emission rate: 561.1-661.4μg/min per stick
  - Emission factors: 19.8-43.6 mg/g; 32.6-52.7 mg/stick
  - Higher than one cigarette: 14 ± 4 mg $PM_{2.5}$
- PAHs
  - Emission rate
  - Emission factors 17.1-25.2 μg/g; 28.3-30.5 μg/stick
  - Higher than one cigarette: 1 μg PAHs

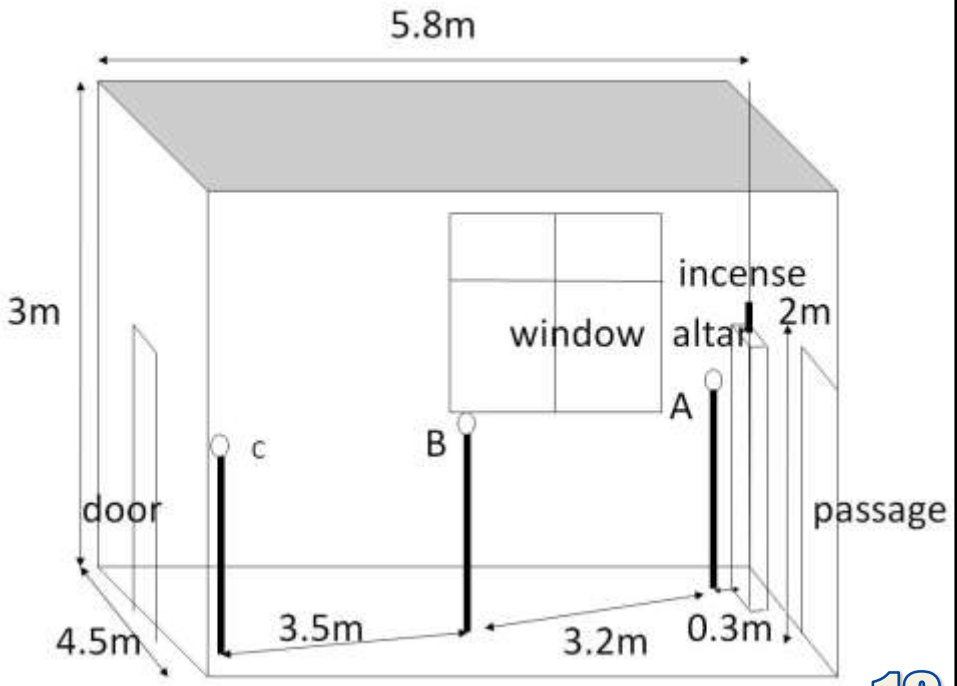


Worshippers' Exposure in Indoor Environments

[**Lung** & Kao, 2003]

- Objectives:
  - quantify indoor PM exposures under two conditions: closed and ventilated
  - examine concentration change with time and distance
- Findings:
  - closed condition: 723μg/m^3, 9 times background concentration,
  - ventilated condition: 178μg/m^3, 1.7~2 times background concentration

- Real household experiments



Worshippers' Exposure to $PM_{2.5}$ in Temples

[**Lung** & Kao, JAWMA, 53, 130-135, 2003]

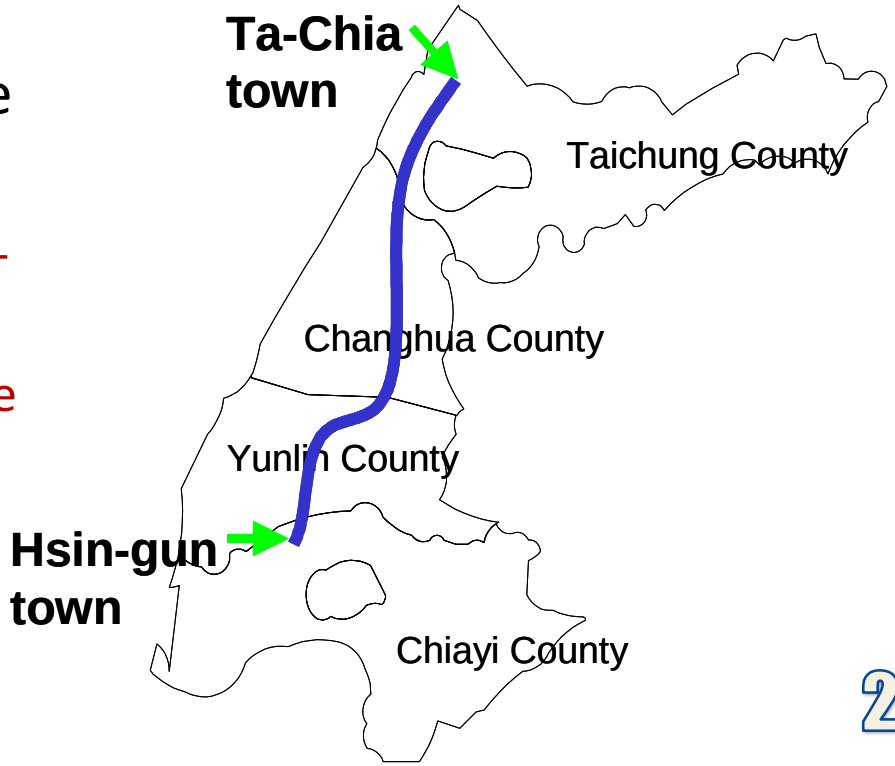
- Objectives：
  - Quantify personal $PM_{2.5}$ exposure of worshippers during temple visits
  - Evaluate the contribution of various exposure factors

- Findings:
  (1) PM inside temples were 4-6 times higher than outside
  (2) Each incense stick in the censer contributed 0.52μg/m^3 to worshippers' exposure
  (3) Exposures in the temple with more censers and sticks used had higher (124μg/m^3) exposure

Exposure To $PM_{2.5}$ and Gaseous/Particulate PAHs during The Ma-tzu Goddess Parade

[Lung et. al, Journal of Exposure Analysis and Environmental Epidemiology, 14(7) 536-543, 2004]

- Objectives: Assess $PM_{2.5}$, gaseous and particulate PAH exposures to paraders
- Findings: Quantifying contribution of various exposure factors
  - $PM_{2.5}$ Exposure in parade were 1.6-2.2 times higher than otherwise
  - Exposure of motorcycle riders were 1.8 times of those of car drivers
  - Incremental $PM_{2.5}$ exposure increase was able to be quantified for every minute in temples



Year 1999-2004

Indoor Air 2003; 13: 194–199
www.blackwellpublishing.com/ina
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INDOOR AIR
ISSN 0905-6947

Contribution of incense burning to indoor PM_{10} and particle-bound polycyclic aromatic hydrocarbons under two ventilation conditions

TECHNICAL PAPER

ISSN 1047-3289 *J. Air & Waste Manage. Assoc.* 53:130–135

Abstract Burning incense to wo
prevalent in Asian societies. Th
resulting from incense burning

Worshippers' Exposure to Particulate Matter in Two Temples in Taiwan

Journal of Exposure Analysis and Environmental Epidemiology (2004) 14, 536–543

www.nature.com/jea

Participants' exposure to $PM_{2.5}$ and gaseous/particulate polycyclic aromatic hydrocarbons during the Ma-tsu Goddess parade

PERGAMON

SHIH-CHUN CANDICE LUNG,[a,b] KAI-JUNG GUO,[b] PENG-YU CHEN,[b] PEI-FUNG TSAI,[b] AND PI-CHUEN CHEN[b]

Generation rates and emission factors of particulate matter and particle-bound polycyclic aromatic hydrocarbons of incense sticks

Shih-Chun Candice Lung [a,b,*], Shu-Chuan Hu [a]

[a] *Department of Public Health, Chung Shan Medical University, Taichung, Taiwan, ROC*
[b] *Institute of Earth Sciences, Academia Sinica, P.O. Box 1-55, Nankang, Taipei 11529, Taiwan, ROC*

Winner of “Chiu-sen Award 秋森獎 ” in 2004
from Chinese Association for Aerosol Research in Taiwan

- For contribution of incense-burning research, exposure characterization, and exposure factor evaluation for PM and particulate PAHs

My scientific findings got local press's attentions

中華民國八十九年十月七日／星期六 民生報

寺廟懸浮微粒 為居家5～16倍

長期吸入 恐有害健康

廟宇懸浮微粒 比馬路多4倍

燒香、烹飪、抽菸可能與肺癌日增有關 研究人員建議廟方常清理香爐

記者洪淑惠／台北報導

燒香拜拜 煙霧瀰漫 懸浮微粒 易使人罹癌

公衛調查提警訊 遠廁勿離香爐太近 在家保持通風良好

Causing cancers

中華民國九十二年五月五日／星期一 民生報

初一、十五進香 致癌風險更高

研究顯示 暴露在多環芳香烴環境中 風險是一般人的1000倍 寺廟人員及每日在家中佛堂燃香者 也達警戒標準

你燒那種香？

烏香較貴 燃燒產生致癌物也多

沈香便宜 排放多環芳香烴較少

Yahoo!奇摩 新聞

新聞首頁 > 健康新聞 > 聯合新聞網

日常生活細小懸浮微粒 致命毒素

空氣汙染危害健康，但人們日常活動所造成的懸浮微粒暴露濃度到底多少？中央研究院環境變遷研究中心助理研究員龍世俊昨天指出，其實人們在運動、烹調、燒香拜拜、甚至到餐廳吃飯都無時無刻不暴露在懸浮微粒汙染中，累積致命毒素。

明日報 www.tTIMES.com.tw

健康104

寺廟香煙裊裊有害健康 香客宜遠離香爐

2000/10/06 11:37 | 台北 報導

燒香拜拜是中國人特有宗教習慣，尤其在初一、十五，寺廟更是香煙裊裊、香火鼎旺。不過，根據中山醫學院公共衛生系教授龍世俊針對燒香對人體的危害進行研究，發現寺廟內的懸浮微粒是一般居家的5到6倍，而初一、十五的懸浮微粒更高於平常，其中成份如多環芳香烴更是致癌物，可能影響健康。

Year 2014-2015 and on-going movement

Wed, Aug 27, 2014 - Page 1 News List

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Xingtian's ban on incense upsets vendors, not visitors

By Yeh Kuan-yu / Staff reporter, with CNA

- On average, 2.5 registered temples in each community in Taiwan, accounting for a significant portion of $PM_{2.5}$ emission in Taiwan

Tue, Jun 16, 2015 - Page 3 News List

Print Mail Facebook Twitter plurk funp

Longshan Temple halves censers used in worship

SPIRITUAL POLLUTION: The policy change follows earlier measures to cut the number of sticks used in worship, as well as refusing to accept donated incense

By Abraham Gerber / Staff reporter

Longshan Temple (龍山寺) in Taipei yesterday closed access to more than half of its censers following concerns over incense smoke polluting the surrounding area.

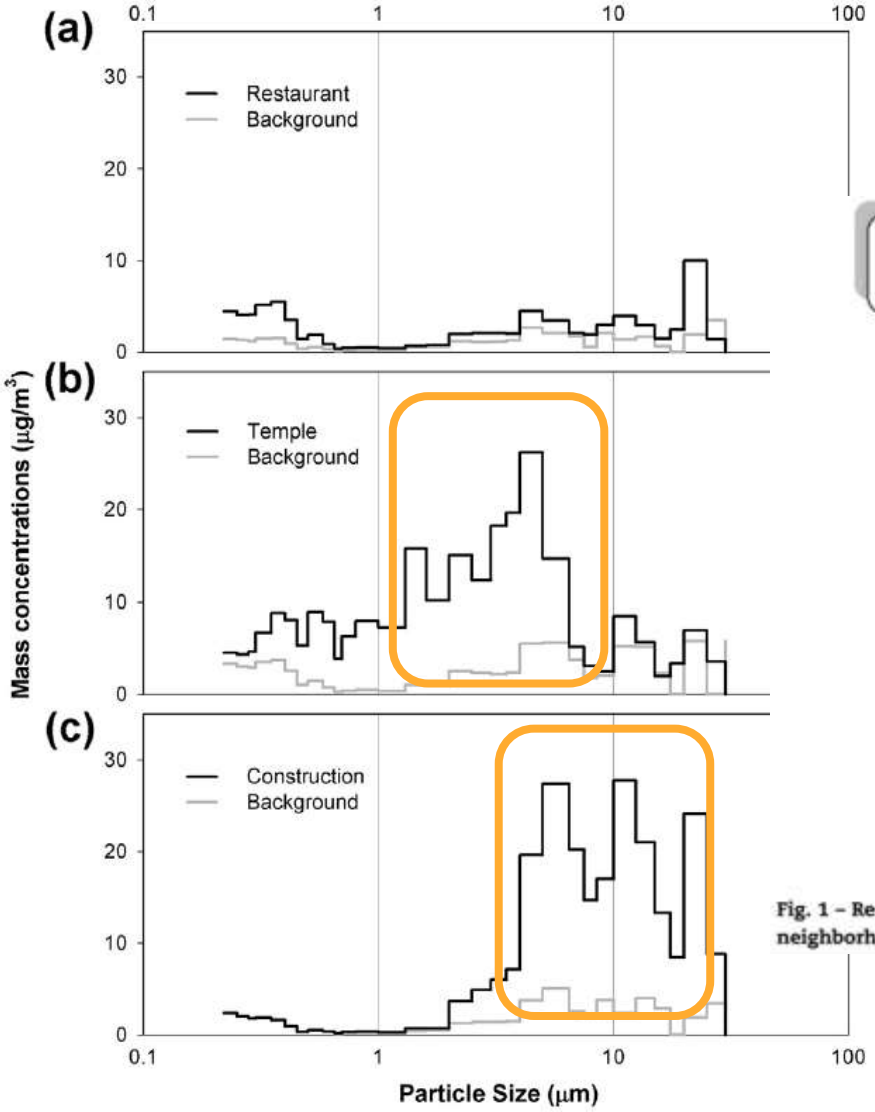
Red lids capped four of the temple's seven censers, as the temple prepared to move them into storage.

http://www.taipeitimes.com/News/front/archives/2014/08/27/2003598362

http://www.taipeitimes.com/News/taiwan/archives/2015/06/16/2003620830

Variability of intra-urban exposure to particulate matter and CO from Asian-type community pollution sources

[Lung et al., Atmospheric Environment, 83:6-13, 2014]



Inequality of Asian-type neighborhood environmental quality in communities with different urbanization levels

[**Lung** et al., Environmental Science & Policy, 38:1-10, 2014]

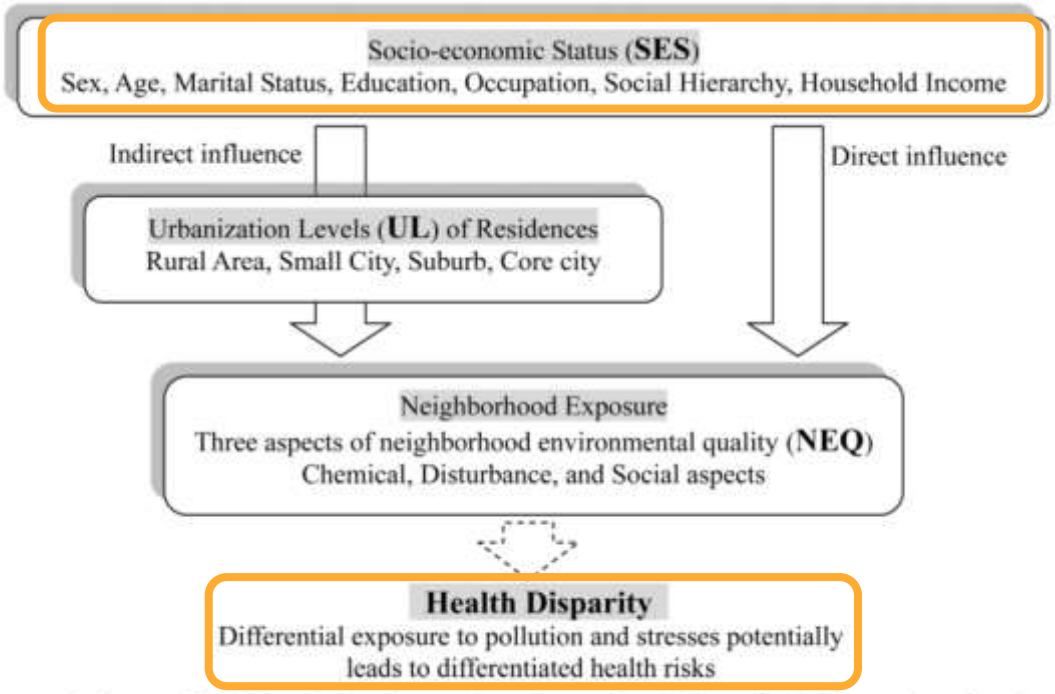


Fig. 1 – Research framework of this study, focusing on the pathways of social inequality leading to inequality of neighborhood exposure, which may in turn result in health disparity.

Light-weight sampling, monitoring, and sensing devices for personal exposure assessment

Before year 2000
Personal PM sampler (PEM) with a pump weight 2kg

After year 2000
GRIMM real-time PM monitor

Year of 2017 Wearable PM sensor. Less than 200g with GPS and wifi

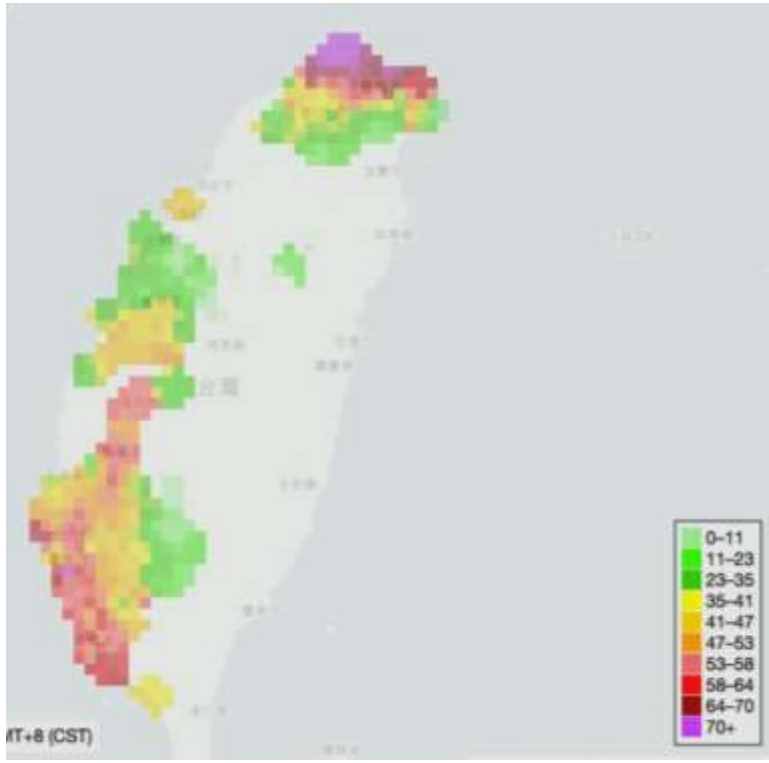
Application of PM sensors in Atmospheric Chemistry Research

■Street-level monitoring system

- Research-grade
- Weather-proof
- Wireless transmission
- High time resolution
- $PM_{2.5}$, Temperature, RH% and CO_2
- Less than US$700 per set
- In the future, other chemical sensors can be deployed

- Engaging citizens to deploy thousands sensors (education version) in Taiwan
- Pollution transport case from the north to the south of Taiwan on 2017/1/30

[L-J Chen, 2017]



https://giphy.com/gifs/tw-2017130-0715-1655-l3q30gLatC3ZHUjYs

Summary and Suggestions

- Co-benefit thinking to link Atmospheric Chemistry to Health-related Air Pollution Research and Pollution-Reduction Policy
  - What are the controllable factors that our studies can identify? (Lab, monitoring, and modeling studies)
  - What policy recommendations can we make based on our study results that can further reduce air pollution levels?
- Cross-scale studies to link local, regional, and global scales of research gaps to reduce pollution levels and have co-benefits on climate and health

Co-benefit Thinking to Link Atmospheric Chemistry Research to Pollution-Reduction Policy

Thank you very much for your attention!

Shih-Chun Candice LUNG 龍世俊

Research Center for Environmental Changes, Academia Sinica

Center for Sustainability Science , Academia Sinica

Sc.D, Harvard University, School of Public Health

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Students, research assistants, post-docs, and collaborators for conducting these studies !