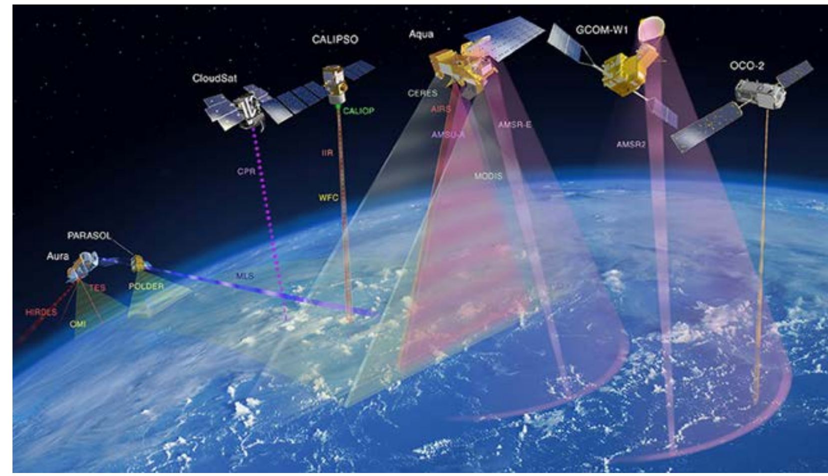
EVS341

Monitoring Human Exposure to Environmental Pollutants: Air Pollution



Dr Eloise Marais • Birmingham Fellow • e.a.marais@bham.ac.uk

Weeks 3-5 Learning Outcomes

Equip you with the knowledge to develop an air quality monitoring strategy

Meaningful contribution to public discourse/debate on AQ in the UK and beyond

Exposure Assessment Strategy

Considerations when designing an effective exposure assessment strategy.

TODAY

Terminology

Measurement and modelling technology

WEEK 4

Air Pollution Sources

Health Outcomes

Costs of air pollution

Benefits of mitigation

WEEK 5

Legislation

Compliance

Historical Perspective: Air Pollution & Health

Pre-industrial wood burning

London landmarks during the smog event of 1952

Los Angeles in 1968

Beijing today

New Delhi today

Air pollution present in homes before the industrial revolution (woodburning)

1952 London smog associated with 6,000 deaths. 25,000 people claimed sickness benefits (politics of 1952 smog features in Netflix series The Crown)

Development in the US, Europe, China, and India follow a predictable trajectory

Relationship Between Sources and Health Effects

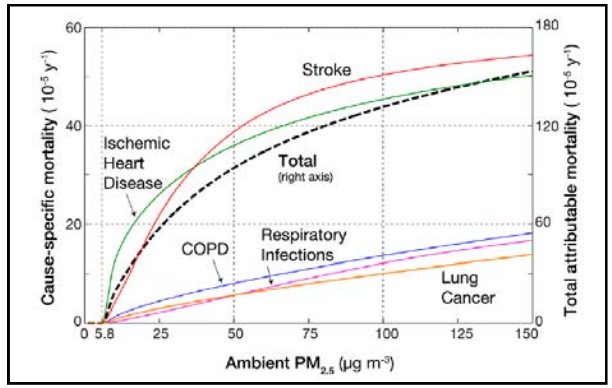
Health outcomes and **exposure times**:

Exposure Time	Pollutant	Health Outcome
Short term (acute)	Particles (PM)	Cardiac arrest
Long term (chronic)		Lung cancer

Air Quality Assessment

What are the sources?

What is the impact?



COPD: Chronic obstructive pulmonary disease

[Apte et al., 2015]

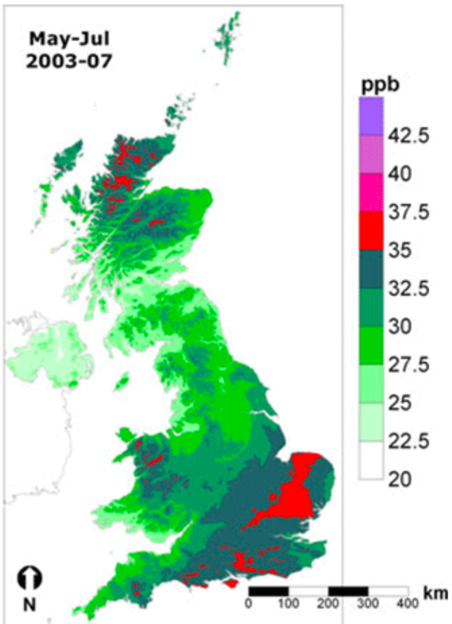
How mitigate?

Is there compliance?

Terminology

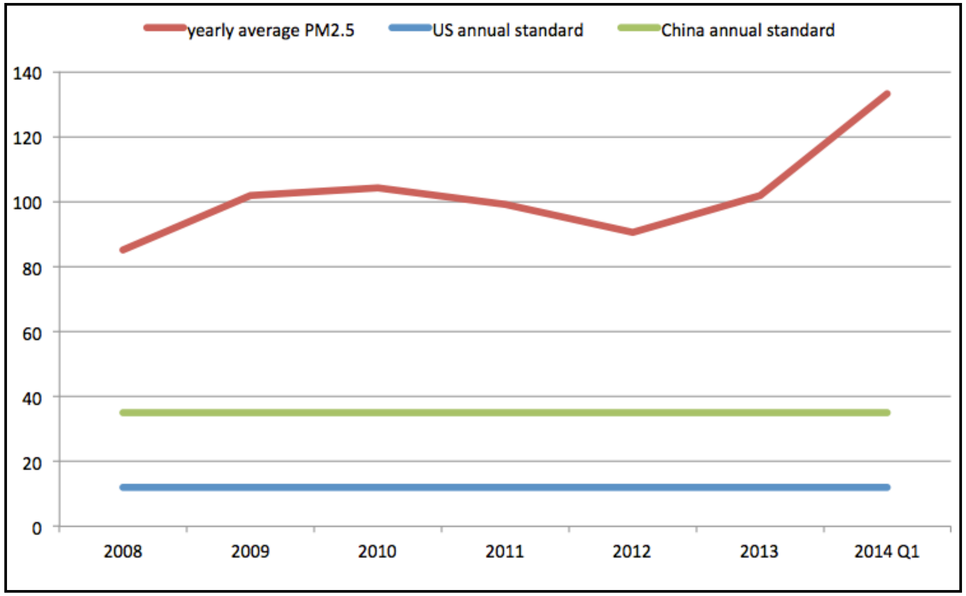
Concentration: amount or abundance of a pollutant

Surface ozone in the UK



Source: http://www.apis.ac.uk/overview/pollutants/overview_O3.htm

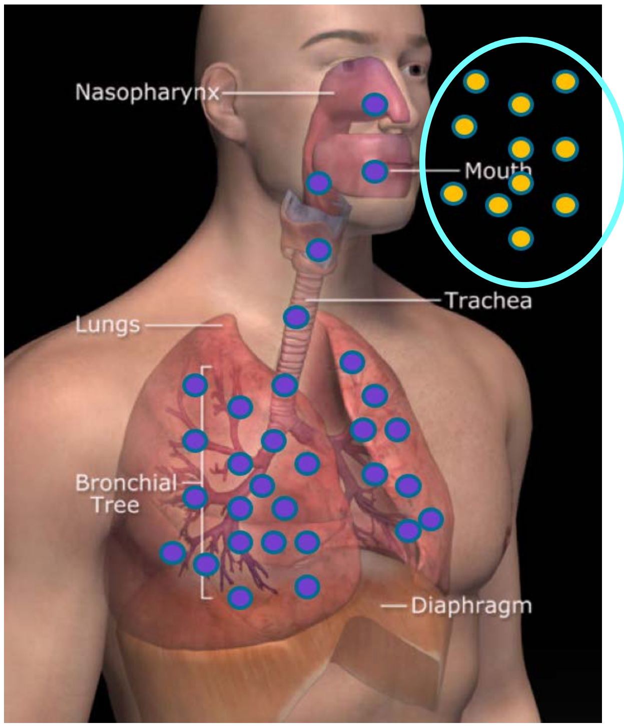
Fine particles ($PM_{2.5}$) in $\mu g\ m^{-3}$ in Beijing



Source: http://www.livefrombeijing.com/

Terminology

Exposure: Pollution in contact with a target population.



Personal exposure

$$PE = \frac{\Sigma C_{ME} \cdot t_{ME}}{\Sigma t_{ME}}$$

PE = Personal Exposure in microenvironments (µg/m^3)

$\mathbf{C_{ME}}$ = Concentration in microenvironment (µg/m^3)

$\mathbf{t_{ME}}$ = Time in microenvironment (min)

Worked Example

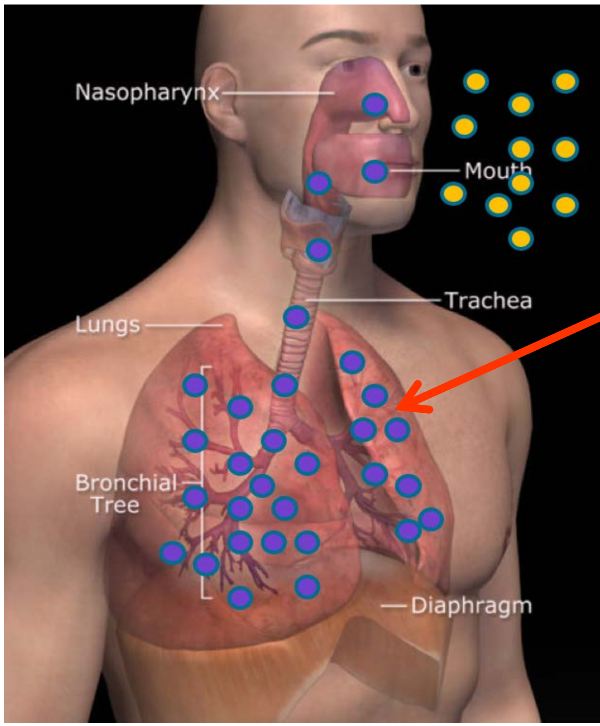
Test your understanding

Task: Calculate my exposure to fine particles ($PM_{2.5}$) from the start of this lecture to tomorrow morning.

Information: I spend 2 hours in this classroom that has a $PM_{2.5}$ concentration of 19 $\mu g\ m^{-3}$, go back to my office to work for 2 hours at the same $PM_{2.5}$ concentration, then go for a run for 1 hours outside along a route with fairly uniform concentration of $PM_{2.5}$ of 8 $\mu g\ m^{-3}$, 30 min to walk home from work after my run and the concentration has increased slightly to 10 $\mu g\ m^{-3}$, then watch Netflix for 2 hours, because I'm very engrossed in what's happening in Season 3 of Narcos. The concentration in my home is 30 $\mu g\ m^{-3}$ because my husband just cooked dinner. I go to sleep for 8 hours. Some of the $PM_{2.5}$ has settled out and it stabilizes at 12 $\mu g\ m^{-3}$.

Terminology

Dose: amount of pollutant inhaled
(e.g. μg benzene inhaled per day or μg day^{-1}).



Lung Dose

$$D_L = \frac{\Sigma C_{ME} \cdot t_{ME} \cdot V_{ME} \cdot Eff}{\Sigma t_{ME}}$$

$\mathbf{D_L}$ = Lung Dose (μg)

$\mathbf{V_{ME}}$ = Minute ventilation in each microenvironment (m^3/min)

Eff = Efficiency of deposition (particles) or absorption (gases)

Ventilation rates proposed by the ICRP model (L/min)(ICRP, 1994).

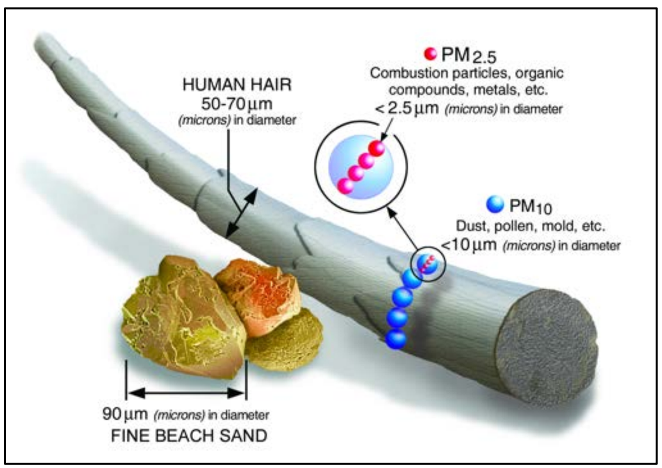
		Resting	Sitting awake	Light exercise	Heavy exercise
VE	Male	7.5	9	25	49
	Female	5.3	6.4	20.8	45

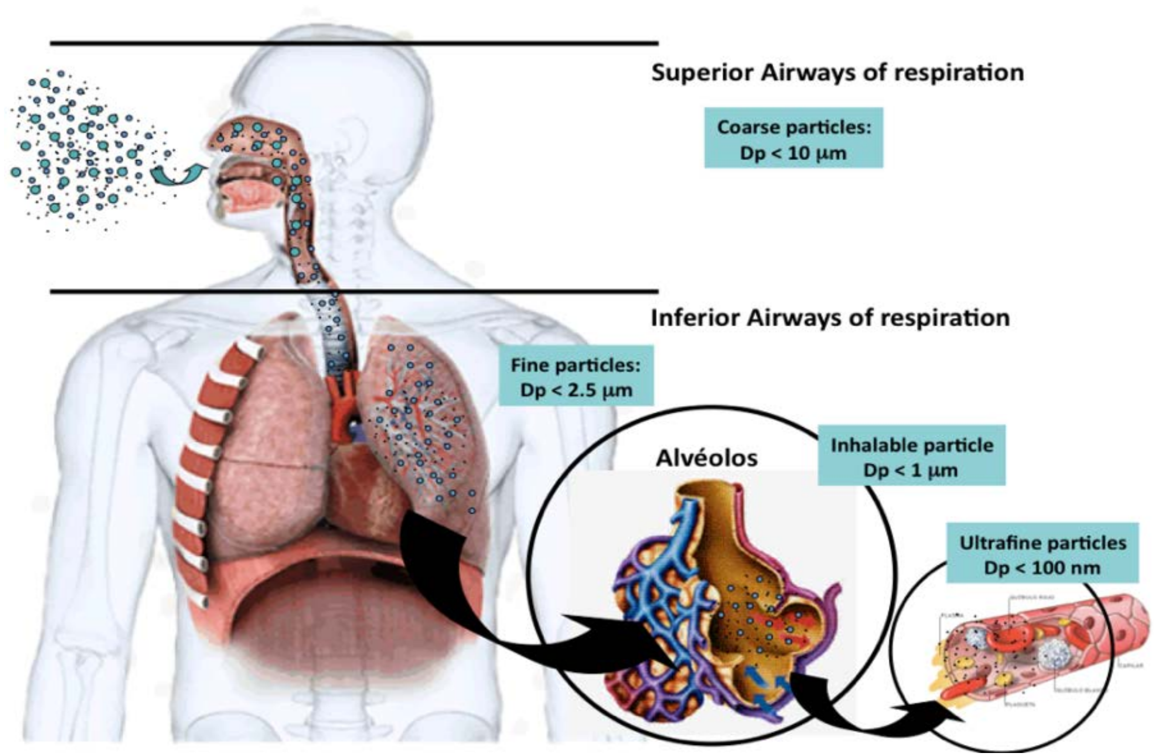
Aerosol Deposition Efficiency

The smaller the particle, the further it travels through the lungs

Larger particles settle out (deposit)

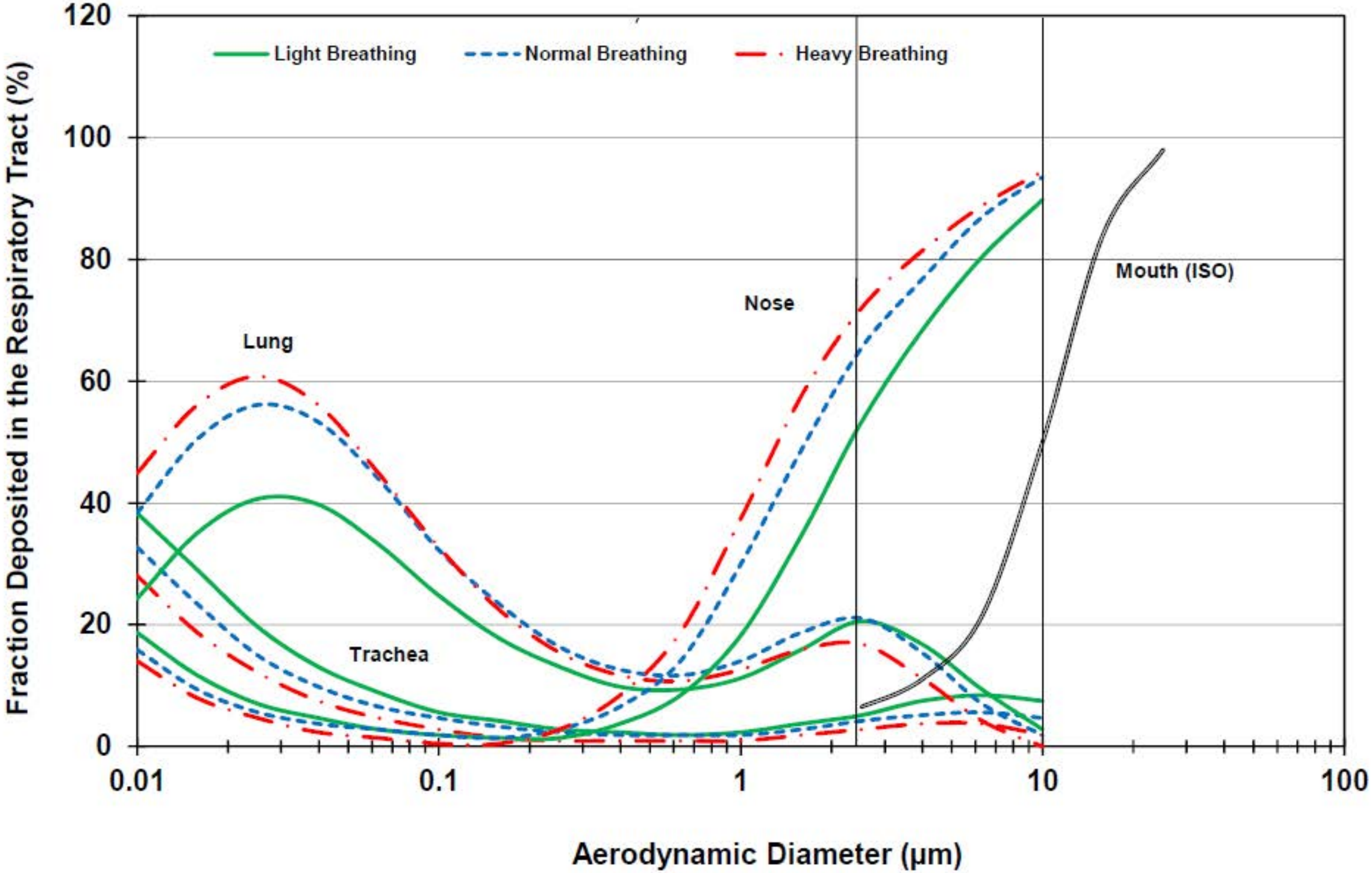
Sense of scale





Aerosol Deposition Efficiency

The amount of particles that deposit depends on a person's breathing rate



Aerodynamic diameter: diameter of a spherical particle with the same volume as an irregularly shaped aerosol particle.

Worked Example Revisited

Test your understanding

Task: Calculate my lung dose.

Information: I spend 2 hours in this classroom that has a $PM_{2.5}$ concentration of 19 $\mu g\ m^{-3}$, go back to my office to work for 2 hours at the same $PM_{2.5}$ concentration, then go for a run for 1 hours outside along a route with fairly uniform concentration of $PM_{2.5}$ of 8 $\mu g\ m^{-3}$, 30 min to walk home from work after my run and the concentration has increased slightly to 10 $\mu g\ m^{-3}$, then watch Netflix for 2 hours, because I'm very engrossed in what's happening in Season 3 of Narcos. The concentration in my home is 30 $\mu g\ m^{-3}$ because my husband just cooked dinner. I go to sleep for 8 hours. Some of the $PM_{2.5}$ has settled out and it stabilizes at 12 $\mu g\ m^{-3}$.

Exposure Assessment Technology

Broad categories of available exposure assessment methods

[guided by Zou et al., 2009]

- **Environment Monitoring**
  - ➢ Indoor
  - ➢ Outdoor
- **Exposure Monitoring**
- **Modelling**
  - ➢ Air Dispersion Model
  - ➢ Hybrid Model
  - ➢ Human Inhalation Model
  - ➢ Machine Learning
- **Biomarkers of Exposure**

By no means an exhaustive list!

Quality of Measurement Technique

Many Metrics to Consider:

Accuracy – proximity to true value

Precision – repeatability and reproducibility (standard deviation)

Sensitivity – response to a change in concentration

Limit of Detection – lowest concentration distinct from zero

Measurement Range – range over which reliably measure

Instrument Drift – shift in performance of instrument

Interference – multiple compounds detected simultaneously

Systematic error – induces a bias (affects *accuracy*)

Random error – random bias in a single measurement (affects *precision*)

How determine?

Compare to standards in the laboratory (compare against known value)

Compare to tried and tested method

Search the literature

Environment Monitoring

Indoor Air Quality

Home or Work (microenvironment) pollutant concentrations as a surrogate of personal exposure (PE)

Use to obtain a relationship between concentration and exposure

Issues:

Relationship does not hold if person moves through multiple environments

Does not factor in activity type of the person

Environment Monitoring

Outdoor Air Quality

- Stationary monitors: widely used, accurate, costly, gaps
- Mobile monitors: not always practical, limited in location and time
- Low-cost sensors: new approach, inexpensive, technical challenges
- Issue: not always representative of PE

Stationary Monitor

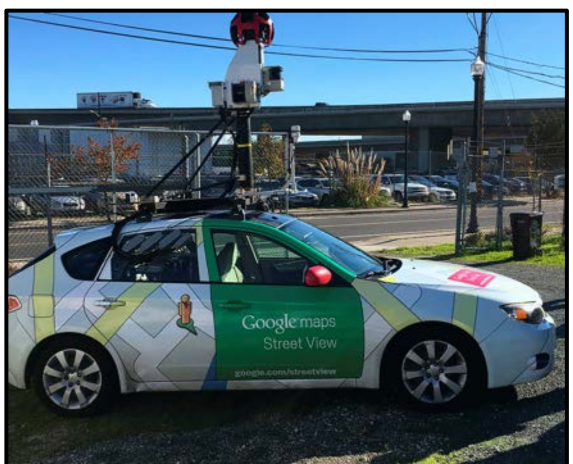
UK DEFRA network

Index Bands

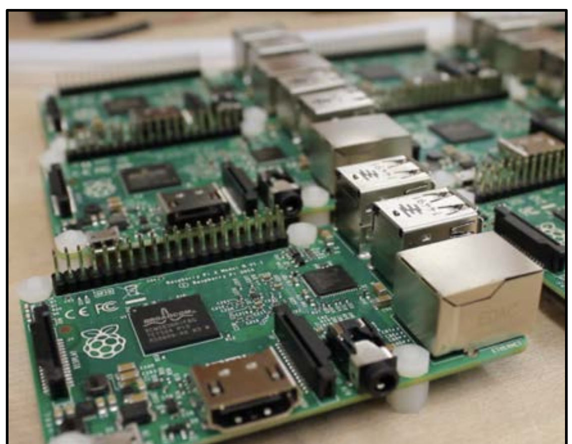
1	2	3	4	5	6	7	8	9	10
Low			Moderate			High			Very High

http://uk-air.defra.gov.uk/interactive-map

Mobile Monitor



Low-cost sensors

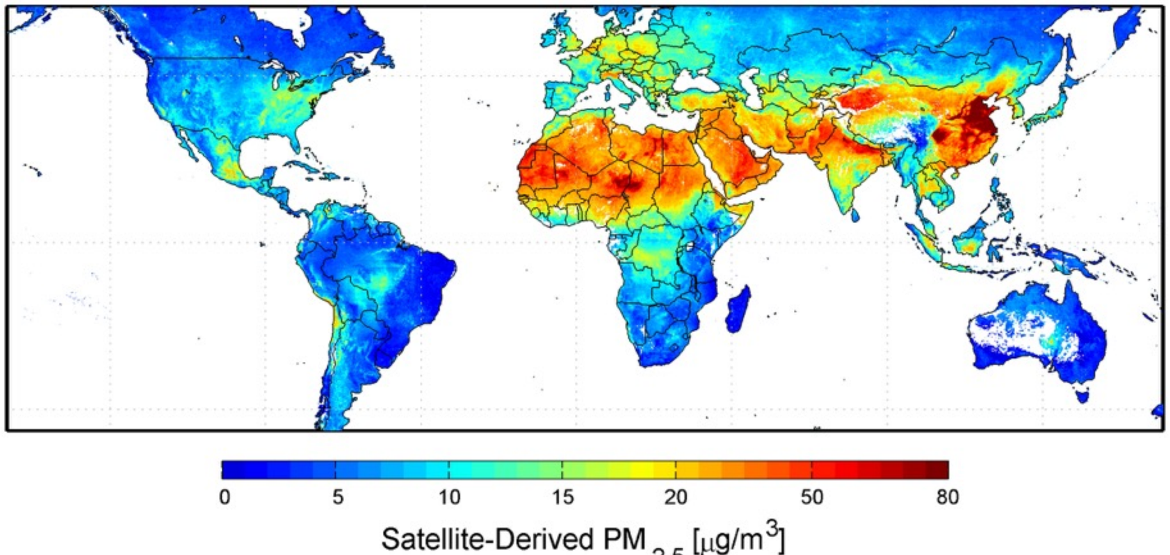


Environment Monitoring

Outdoor Air Quality

Space-based sensors (Earth observations/satellite observations)

Global surface concentrations of fine particles ($PM_{2.5}$) obtained by combining satellites and a 3D global model



Source: van Donkelaar et al., EHP [2010]

<u>Application:</u> estimate worldwide premature deaths to $PM_{2.5}$ exposure

<u>Advantage:</u> complete coverage of the globe

<u>Disadvantage:</u> uncertainties associated with satellite observations and model

Environment Monitoring

Personal Exposure Monitoring

1. Real Time Monitors

2. Active Sampling

3. Passive Sampling

PE Monitoring is considered the most accurate estimate of a person’s true exposure

Environment Monitoring

PE Monitoring: Real Time Monitors

Collection and analysis happen simultaneously

- Monitor exposure to pollutants lethal at low dose, e.g. radiation, lead, asbestos

Environment Monitoring

PE Monitoring: Active Sampling

Pollutant collection and analysis not simultaneous

Pump (ACTIVE) and a sampling device

Pollutant collection:

- Physical: particles on filters, diffusion of gases on sorbents
- Chemical: gases react with substrates

Analysis in the Laboratory:

Particles: gravimetry (mass)
Gases and soluble material: coupled chromatography and mass spectrometry (GCMS, LCMS)
Metals: mass spectrometry (ICPMS), fluorescence (XRF)
Charged compounds (ions): ion chromatography (IC)

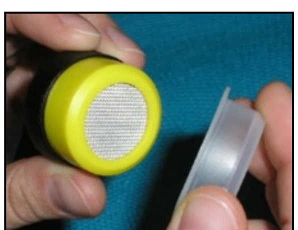
Advantages: Device is reusable

Limitations: Heavy (0.5-1.1 kg)
Short battery life (24 hours)
Need access to laboratory

Environment Monitoring

PE Monitoring: <u>Passive Sampling</u>

Pollutant collection and analysis do not occur simultaneously



Pollutants collected by diffusion (PASSIVE) onto sorbents

<u>Pollutant collection:</u>

- Physical: diffuse
- Chemical: react with substrate

<u>Analysis in the Laboratory:</u>

Gases and soluble material: coupled chromatography and mass spectrometry (<u>GCMS</u>, <u>LCMS</u>)
Charged compounds (ions): ion chromatography (<u>IC</u>)

<u>Advantages:</u> Light weight (< 30 g)
Not limited by battery life
Cheap
Minimal user training

<u>Limitations:</u> Affected by environment (humidity, wind speed, very high pollutant levels)
Only measures gases (no particles)
Need access to a laboratory

Worked Example Revisited

Test your understanding

Issue: The University is concerned that students are exposed to elevated concentrations of airborne dust (that includes metals and ions) during ongoing construction projects. The Vice Chancellor has approached you to ask for recommendations on how to monitor and analyze exposure

Task:
What collection and measurement technique do you recommend and why?

Exposure Modelling

Models: General

What is a model?

What are key components of an AQ model:

Why use a model?

Exposure Modelling

Models: General

What is a model?

Attempt at representing reality.

<u>Exposure Model:</u> estimation of exposures and doses of air pollutants of an individual, sub-group of a population or whole population.

What are key components of an AQ model:

Why use a model?

Exposure Modelling

Models: General

What is a model?

Attempt at representing reality.

Exposure Model: estimation of exposures and doses of air pollutants of an individual, sub-group of a population or whole population.

What are key components of an AQ model:

(As you will see in the slides that follow, the architecture of models vary)

- Meteorology (wind, air temperature, rain)
- Land cover types (trees, soil, road)
- Emission inventories (location and magnitude of pollution sources)
- Chemistry (formation and loss processes of pollutants)

Why use a model?

Exposure Modelling

Models: General

What is a model?

Attempt at representing reality.

<u>Exposure Model:</u> estimation of exposures and doses of air pollutants of an individual, sub-group of a population or whole population.

What are key components of an AQ model:

(As you will see in the slides that follow, the architecture of models vary)

- Meteorology (wind, air temperature, rain)
- Land cover types (trees, soil, road)
- Emission inventories (location and magnitude of pollution sources)
- Chemistry (formation and loss processes of pollutants)

Why use a model?

- Estimate air pollution in locations not covered by monitoring sites
- Assess pathways of exposure to air pollution
- Estimate health outcomes
- Determine future (forecast) and reconstruct past (hindcast) air quality
- Test the effect of mitigation strategies on air quality.
- Determine the most effective locations for monitoring air quality.

Modelling

Proximity Models

Most simplistic.

Assumption: People closest to pollution source have highest health risk.

Example:
Residence living near busy road

Issues: Assumption does not always hold (complex meteorology, chemical reactions, human activities).

Variations: Add layers of complexity: roadd type, land type, traffic flow, elevation.
→ **Land-use regression** (LUR) **models**.

Modelling

Air (Pollution) Dispersion Models

Calculate dispersion/distribution of pollutants

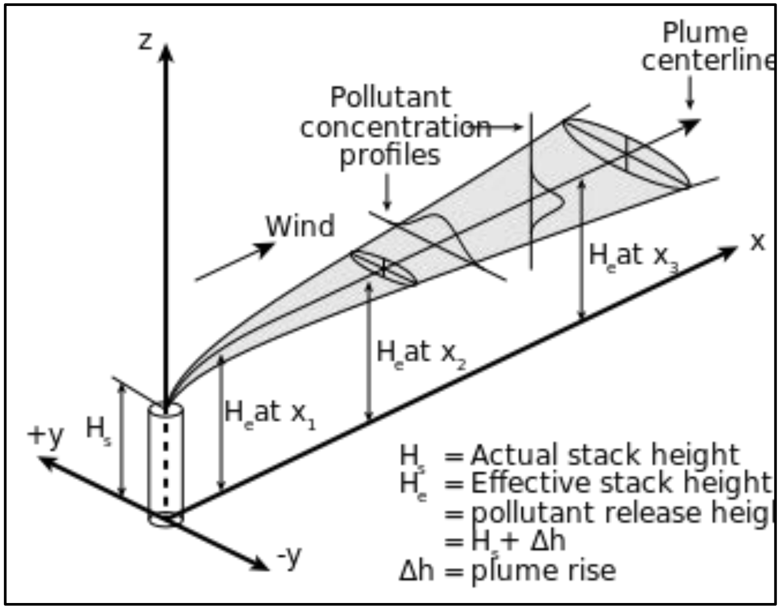
Includes:
- Emission inventories
- Simple meteorology
- Background concentrations from monitoring stations.

Variations: Combine with geolocation data to estimate individual exposure

Advantages:
- Address lack of surface monitoring.
- Design effective ground monitoring networks.
- Flexible (different spatial scales)

Issues:
- Doesn't represent links between source and exposure
- Assumes a dispersion pattern (e.g. Gaussian)
- Monitoring data can be inadequate
- Can be costly

Air pollutant dispersion model



Examples:
CMAQ (US), ADMS (UK), Airviro (Sweden), HAMS-GPS (India)

Modelling

Hybrid Models

Broad class of combined monitoring and/or modelling tools.

Reason/Intention: combine strengths of existing models or monitoring stations

Many Examples:
- Regional and personal monitoring
- Air dispersion model and personal monitoring
- Coarse-resolution regional (CMAQ) and fine-resolution local (AERMOD) dispersion models

Disadvantages: challenges in integrating models different architectures or different spatial resolutions and measurement frequencies

Modelling

Human Inhalation Models

Chemical inhalation from contact with pollutant

Input required: human activity, physiology, chemical & environmental conditions

Examples:
SHAPE: simulation of human activity and pollutant exposure

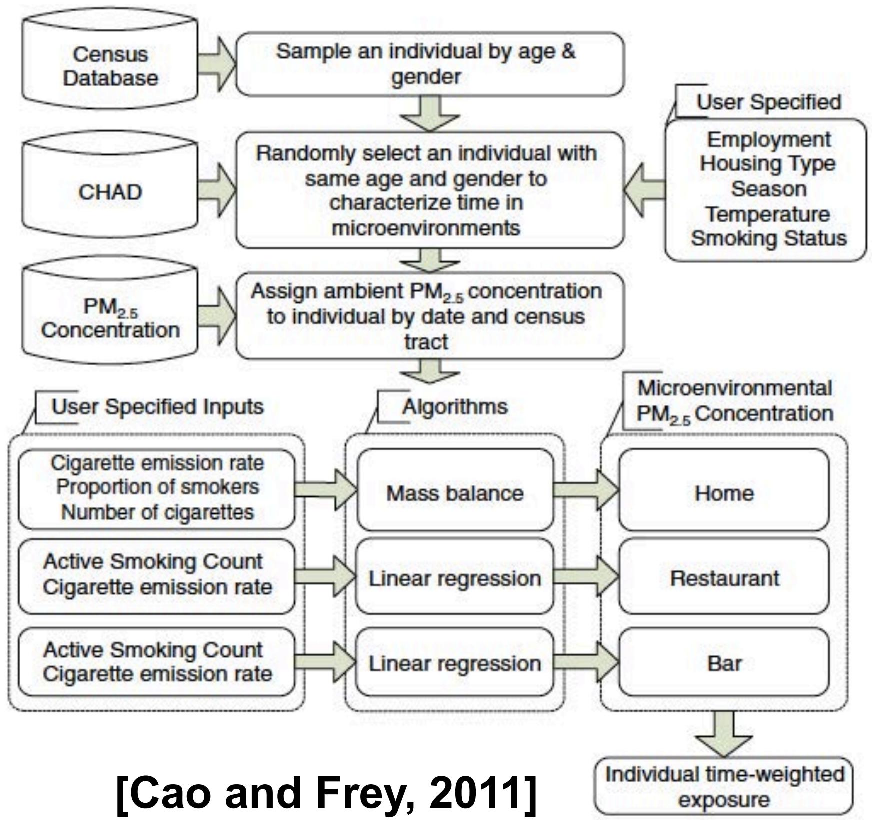
SHEDS: stochastic human exposure and dose simulation

APEX: air pollutants exposure model

Advantage: link exposure to air pollution and health effects

Disadvantage: needs time-activity data.

SHEDS-PM for tobacco smoke



[Cao and Frey, 2011]

Modelling

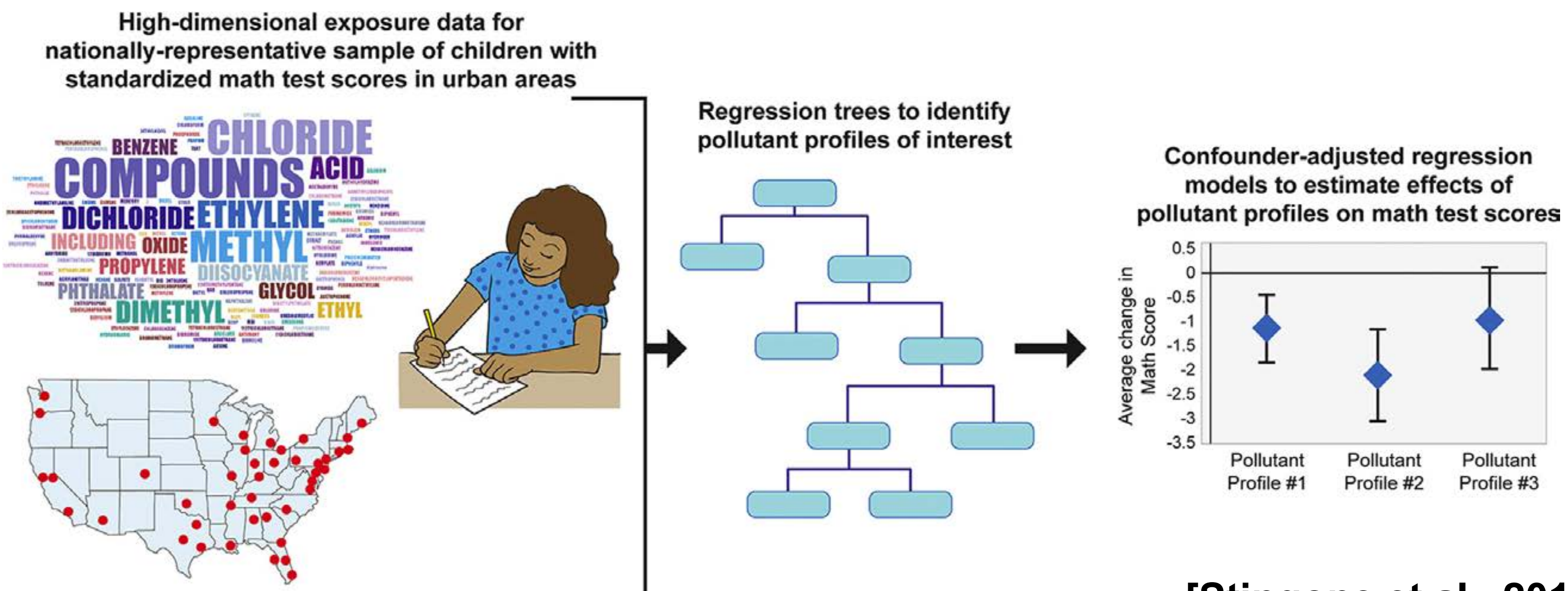
Machine Learning

Use a training dataset to teach a computer to perform a task

<u>Everyday examples:</u> filter emails (spam/priority), customized advertising, newsfeed algorithms

<u>Air pollution applications:</u> predict health effects due to air pollution.

Illustration of Approach



[Stingone et al., 2017]

Biomarkers

Biomarker of exposure:
Chemicals or chemical metabolites in the body (blood, saliva) or external to the body (excretion, hair).

Biomarker of effect:
Change in a human due to exposure to pollution indicating a health effect.

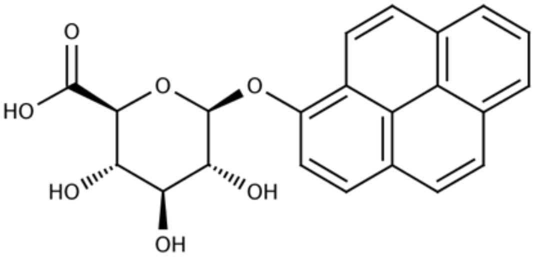
Biomarkers

Test your understanding

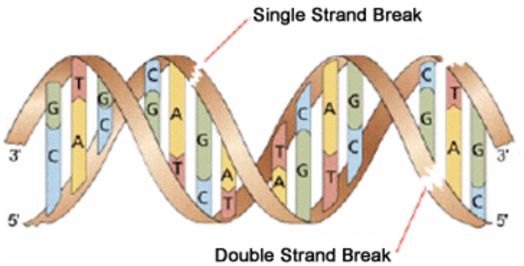
A study is conducted to determine the health effect of exposure of traffic conductors/controllers $PM_{2.5}$ and PAHs from traffic emissions.

Measurements are made of a PAH in the urine and of DNA strand breaks.

Traffic conductors



PAH measured in urine



DNA strand breaks

What is the biomarker of exposure and of effect?

Practical Considerations

1. Economic

- Cost: device, analysis, labour, computers.
- Reusability

2. Logistics

- Mobility
- Noise level
- Volunteer willingness

3. Scientific Outcome

- Compounds measured
- Instrument quality
- Sampling frequency
- Appropriateness for PE

Worked Example

Thought Experiment

Task: The Birmingham City Council seeks the services of your Consultancy company to determine personal exposure to $PM_{2.5}$ at a bus stop along the A4040.

Questions to get you started:

What monitoring strategy would you use?
Why?
What are the advantages of this approach over others?
What would it cost?

Is there additional information do you need to effectively assess roadside pollution exposure?

Chronic Inhalation/Intake

Chronic: long-lasting disease caused by regular exposure to a harmful substance over a prolonged period, e.g. chronic bronchitis, respiratory disease.

$$\text{Chronic Inhallation Intake} = \frac{\text{CA} \times \text{IR} \times \text{ET} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT}}$$

Intake: Amount of pollutant (mg) per kg body weight per day

CA: pollutant concentration (mg per m^3 air)

IR: inhalation rate (m^3 air per hour)

ET: exposure time (hours per day)

EF: exposure frequency (days per year)

ED: exposure duration (years)

BW: body weight (kg)

AT: time period over which exposure is averaged (days)

Example of application:

Assess intake of the carcinogen benzene by a factory worker that has worked 8 hours each weekday at a factory with elevated benzene levels for 30 years