Population based long-term air pollution exposure assessment
...in Epidemiological Studies

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OEIH&S course
Before we start...

- **Exposure** = contact of target with a pollutant (duration is critical NOT SAME AS ‘CONCENTRATION’)
- **Personal exposure** = exposure near body (assessed generally carrying monitors by study participants)
- **Epidemiology** = the study of the patterns, causes, and effects of health and disease conditions in defined populations.
- **Short-term vs long-term exposures ~ acute vs chronic health effects** (Short term usually hourly, daily; long-term annual or decades)
Exposure Science has its roots in industrial hygiene

- Workplace: who, what, when, where, and why?
- 19th C. air quality in coal mines ($\text{CO}_2$, $\text{O}_2$, dust...)
- Methods to measure physical & chemical hazards in industry (metal fumes, benzene, silica, asbestos, PAHs, VOCs, noise, heat...)

![Images of industrial settings]
Three Components of Exposure Science

- Monitoring
- Modeling
- Assessment
Pollutants monitoring is central to Exp. Ass.

Exposure to particulate matter with an aerodynamic diameter of 10 μm or less (PM10) in 1081 cities, 2003–2010

Outdoor PM$_{10}$ distribution across the globe

The boundaries and names shown and the designations used on this map do not imply the expression of any opinion whatsoever on the part of the World Health Organization concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. Dotted lines on maps represent approximate border lines for which there may not yet be full agreement.

Data Source: World Health Organization
Map Production: Public Health Information and Geographic Information Systems (GIS) World Health Organization

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Criteria air pollutants

• US EPA, EEA, CPCB and other national regulatory agencies use six "criteria pollutants" as indicators of outdoor air quality.

• For each of them a maximum concentration above which adverse effects on human health may occur, is established - referred as NAQQS.

**CO, NO₂, SO₂, PM₁₀, Pb & O₃**
Air pollution measurement methods: some considerations

- Fixed site vs. mobile/personal measurements
- Cost vs. performance
- Time-integrated vs. continuous
- Reference vs. custom/ in-house methods
- Sample collection vs. analysis of component of interest (e.g. for particles)
- Sampling vs. instrumental bias/uncertainty
- Various methods for particles depending on PM metric focus; for gaseous more straight-forward
Particulate Matter – size matters!

Recent focus on ultrafine and nanoparticles (<100 nm size) especially in urban areas.
Fundamentals...

Gravimetric methods - Particles

- Filter substrates are collected using impactors/cyclones (for desired size) and designed flow rate (with a suction pump)
- Collected filters are conditioned in laboratory & weighed with precision microbalance

Haerkingen NABEL station

EES/SwissTPH filter weighing facility
Continuous methods - particles

TEOM, Tapered Element Oscillating microbalance, gravimetric (PM<sub>x</sub> mass)

CPC, UFP particle counter, laser/optical (> 4nm)

APS, Particle size analyser counter, optical (0.3-10 μm)

SMPS, Scanning mobility particle sizer, diffusion charging / optical (4nm-700nm)

MAAP, Black Carbon monitor
Time-integrated (passive) methods - Gases

- Gases are collected in tubes/badges by diffusion
- Absorption substrate inside are coated with chemicals (e.g. triethanolamine for NO₂)
- Post-collection analysed in wet-labs using colorometry
Continuous methods - Gases

Passive samplers with electrochemical sensors; usually CO, CO₂, NOₓ, O₃, HCHO, NH₃ etc. can be measured.

Stacked reference gas monitors at NABEL station; all gases are actively sampled and analysed in real-time.
Our Monitoring Methods

• **NO₂**
  o Passive Passam tubes
  o 2-week integrated

• **Gravimetric PM₂.₅/PM₁₀**
  o PM₂.₅ & PM₁₀ with Harvard impactors (HI)
    (at 4 L/min)
  o 2-week integrated

• **Ultafine Particle counts**
  o miniDiSC & PTrak (1-minute resolution)

• **Continuous PM₂.₅/PM₁₀**
  o Dusttrak (1-minute resolution)
  o pDR (1-minute resolution)

• **Continuous BC**
  o microAeth (1-minute resolution)
Exposure modeling

“Essentially, all models are wrong, but some are useful.”

– George Box
Exposure Modeling

→ Use limited exposure measurements to model over area of interest

Ex: a Land Use Regression model (GIS data):

\[ \text{NO}_2_i = \beta_0 + \beta_1(\text{traffic})_i + \beta_2(\text{land use})_i + \beta_3(\text{pop})_i \ldots + \beta_n(\text{pred } x)_i \]

SAPALDIA2 NO2 measurements & model
Liu et al, Atmos Environ, 2012)
Complexities of modeling

⇒ Assumptions

- Characterize:
  1. Source
  2. Meteorology
  3. Chemistry
  4. Terrain
- Receptors
  1. Persons, places,...
Sources

- How to characterize?
  1. Constant emissions
  2. E.g., non-reactive
  3. E.g., no sinks
  4. Idealize
- Source types:
  1. Point
  2. Line
  3. Area
Air pollution sources (Anthropogenic)
Wildfires

Southern California wildfires Oct 2003

Fundamentals...

Highest PM$_{2.5}$ observed – 115µg/m$^3$

FP UFP

Rim High School, Lake Arrowhead

USC, Los Angeles, CA
Saharan dust

Image taken at 12:00 UTC. Large dust storm blowing off the NW coast of Africa.
(NOAA, 2006)

Image taken at 7:45 EDT. Saharan dust stretching from Atlantic ocean westward; appears as yellowish brown hue and can cause hazy conditions later.
(NOAA, 2005)
Parameters from the Geographic Information System (GIS) ~exposures proxies

- Distance to the closest main street
- Street lengths within a buffer (20-500 m)
- Traffic counts within a buffer (20-500 m)
- Population density
- Building density
- Apartment density
- Land use categories
- Elevation
GIS information does not quantify exposure, nor sources of pollution
Given a **specific source** of a gas, what is the concentration expected at any given location, under repeated trials or averaged over time?
Dispersion model predictions for \( \text{PM}_{10} \)

Spatial resolution: 200x200 m

Legende

- \( \text{PM10} \) \( \mu \text{g/m}^3 \)
- \( < 10 \)
- \( 10 - 12.5 \)
- \( 12.5 - 15 \)
- \( 15 - 17.5 \)
- \( 17.5 - 20 \)
- \( 20 - 22.5 \)
- \( 22.5 - 25 \)
- \( 25 - 27.5 \)
- \( 27.5 - 30 \)
- \( > 30 \)

Kartografie: METEOSTAT, Bern, 24.11.04
Dispersion model predicts well total PM$_{10}$

(a) PM$_{10}$ in 2000

SAPALDIA areas: $y=1.9+0.87x$ ($R^2=0.68$, N=15)
All sites: $y=5.2+0.72x$ ($R^2=0.55$, N=57)

Measured (µg/m$^3$)

Modelled (µg/m$^3$)

Liu et al. EHP, 2007
Dispersion model does not predict total NO$_2$ within cities very well

Int=6.0
Slope=0.83
$R^2=0.64$

Outdoor NO$_2$ at home (µg/m$^3$)

Dispersion model predictions (µg/m$^3$)

Liu et al. EHP, 2007
Sources of NO₂ in Switzerland

**Lugano**
- Traffic (63%)
- Regional (21%)
- Household (6%)
- Industrial (6%)
- Agri (3%)

**Geneva**
- Traffic (50%)
- Regional (22%)
- Household (17%)
- Industrial (9%)
- Agri (3%)
Final S2 model including components of Dispersion + GIS + Time + Meteorology

R² (N)
Bas: 0.78 (101)
Wal: 0.83 (112)
Dav: 0.86 (67)
Lug: 0.81 (111)
Mon: 0.77 (95)
Pay: 0.83 (124)
Aar: 0.83 (149)
Gen: 0.83 (99)

Measured 2-wk average ratio (home/fixed-site)

Modeled (µg/m³)

Intercept=0.00
Slope=1.00
R²=0.87

Liu et al. AE, 2012
Model limitations...

- The dispersion model relies on high quality emission inventory data
- The dispersion model is not specific to street canyons (and is being refined)
- Only home outdoor concentrations are considered
- Hybrid NO$_2$ LUR model is sensitive to extreme observations (may have been over-fitted)
Individual Exposure Estimation
Exposure Assessment

Combine Relevant Data
1. Questionnaire data on cohort subjects
   - Home & work address history
   - Home characteristics, ...

2. Exposure modeling
   - Estimate historical exposure
     1. Use of fixed site monitoring data
     2. Use previous measurements/models

→ Estimate total subject exposure for period of interest
Purpose of monitoring network(s)

- Monitor state of environment to enforce regulations and to evaluate success of control measures
- For use in scientific studies (e.g. in investigating environmental and/or health effects of air pollution)

More info: http://www.bafu.admin.ch/luft/
‘Good to know’ networks & resources

- **Swiss National Air Pollution Monitoring Network (NABEL)**
  http://www.bafu.admin.ch/luft
- **US Environmental Protection Agency (USEPA)**
  http://www.epa.gov/gateway/science/air.html
- **California Air Resources Board (CARB)**
  http://www.arb.ca.gov/aqmis2/aqdselect.php
- **European Environmental Agency (EEA)**
  http://www.eea.europa.eu/themes/air/airbase/airbase
- **Clean Air Portal/ Clean Air Initiative for Asian Cities (CAI-Asia)**
  http://cleanairinitiative.org
- **Clean Air World/ National Association of Clean Air Agencies (NACAA)**
  http://www.cleanairworld.org/
- **World Health Organization (WHO)**
  http://www.who.int/topics/air_pollution
- **Central Pollution Control Board (CPCB)**
  http://164.100.43.188/cpcbnew/websearch.asp
- **Central Pollution Control Board (CPCB)**
  http://mpcb.gov.in/envdata/envtair.php
SAPALDIA: Swiss cohort study of Air Pollution And Lung Diseases In Adults
**SAPALDIA (a prospective cohort study)**

**Cross-Sectional (S1)**
- 8 Areas
- Interview Health assessment
- Age 18-60, 9'651

**Cohort + (S2)**
- Address Update
- Health assessment
- Age 28-70, 8'047

**Cohort ++ (S3)**
- Address Update
- Health Assessment
- Age 36-78, ~6'000

- **NO2, O3, CO, SO2, Meteorological**
- Dispersion + Pollen
- p NO2, PM10, PM2.5
- Dispersion, p NO2 Pollen, p NO/NO2
- PM10/PM2.5/UFP/ BS+

|------|-------------|----------------|------------------|--------------|----------------|--------------|----------------|
SAPALDIA (a prospective cohort study)

**Exposures**
- Air pollution
- ETS
- Occupational exposure etc.
- Life style
  - Smoking
  - Diet
  - Physical Activity
- Socioeconomic status

**Effect modification**
- Genetics
- Biomarkers
- Co-morbidities

**Functional Parameters**
- Lung function
- Symptoms
- CV-parameters
- BMI & other params

**Diseases**
- **Respiratory Diseases**
  - COPD
  - Asthma
  - Lung cancer
- **Cardiovascular Diseases**
  - Ischemic HD
  - Heart failure
- **Other Chronic Diseases**

Ackerman et al, SPM, 2005
SAPALDIA subjects location & distribution

SAPALDIA1: 1991-1992 (n=9,651)
SAPALDIA2: 2001-2002 (n=8,047)
Aims of the SAPALDIA3 exposure assessment

Overarching aim is to provide the estimates of individual long-term traffic-related air pollution exposures (e.g. for ultrafine particles) of the cohort participants

- To develop a method for assessing within-city contrasts in long-term average concentrations of UFP, PM$_{2.5}$, PM$_{10}$, and NO$_x$ (enhanced LUR models)
- To investigate spatio-temporal variation of ultrafine particles within urban areas
- To explore the long-term spatial relationship with other PM mass metric and co-pollutants (e.g. NO$_2$)
- To investigate infiltration of air pollutant in typical Swiss homes and model indoor exposures
Monitoring Methods - SAPALDIA3

**NO₂**
1. Passive Passam tubes
2. 2-week sampling period

**PM & BS**
- PM$_{2.5}$ & PM$_{10}$ with Harvard impactors (HI) (at 4 L/min)
- 2-week sampling periods

**PN counts**
- miniDiSC & PTrak (1-minute resolution)
- 2-week sampling periods

- **Two weeks in three different seasons**
- **At least 20 different locations (one site collocated with federal/cantonal monitoring station) for PM$_x$/PN and 40 for NO₂**
Saturation monitoring: e.g. NO$_2$ monitoring in Basel
Modeling individual exposures (in SAPLADIA)

Exposure models

- Dispersion models
- Statistical models + GIS
- GIS based parameters (e.g., proximity to major road)

Data from fixed site monitors and other sampling stations

Few fixed sites not sufficient to represent exposure of everybody

But essential for modeling air pollution exposures

Individual exposure estimates
Indoor / personal exposures can be quite different than outdoor exposures and generally show a different temporal variation.
## Indoor NO₂ model SAPALDIA2 (2003)

<table>
<thead>
<tr>
<th>Season</th>
<th>N</th>
<th>Variable</th>
<th>Estimate</th>
<th>SE</th>
<th>Adj R²</th>
<th>RMSE</th>
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<td>Summer</td>
<td>450</td>
<td>Intercept</td>
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<td>0.64</td>
<td>0.71</td>
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<td>NO₂ outdoor conc (µg/m³)</td>
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<td>Gas stove cooking</td>
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<td>Current smoker in the home</td>
<td>1.93</td>
<td>0.67</td>
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</table>

** p < 0.01; * p < 0.05

**Work in progress...**
still almost all health effects examined against outdoor exposures!
Road ahead...

**Personal exposure assessment** to build a time-weighted long-term personal exposure model:

\[
\hat{C}_{\text{personal}} = T_{\text{in,home}} \times C_{\text{in,home}} + T_{\text{in,work}} \times C_{\text{in,work}} + T_{\text{in,elsewhere}} \times C_{\text{in,elsewhere}} + T_{\text{out,home}} \times C_{\text{out,home}}
\]

\[
+ T_{\text{out,work}} \times C_{\text{out,work}} + T_{\text{commute}} \times C_{\text{commute}} + T_{\text{out,elsewhere}} \times C_{\text{central}}
\]

where \( \hat{C}_{\text{personal}} \) is estimated time-weighted individual personal exposure, and \( T \) and \( C \) are total time spent and concentrations in different microenvironments.
Focus needs to be shifted...

Sources of Airborne PM or Gaseous Precursor Emissions

Indicators in Ambient Air (e.g. mass concentration)

Personal Exposure

Dose to Target tissues

Human Health Response

Mechanisms determining emissions, chemical transformations & transport in air

Human time-activity patterns, indoor sources & sinks of PM

Deposition, clearance, retention and disposition of PM presented to an individual

Mechanisms of damage and repair

NRC, Research priorities for airborne PM, 2005
Envt‘l Health Research ↔ AQ regulation

- Health risk assessment
- AQ regulation & New Standards
- Mechanistic lab. & toxicological studies
- Ambient AQ monitoring
- Air pollution exposure assessment
- Epidemiological environmental health research
- National/State monitoring agencies + Specific air monitoring activities
Exposure assessment: future directions (1)

- Need more air monitoring data, and in varied environments and increased efforts on physico-chemical characterization
- Model validation e.g. dispersion models, need specific focus on spatial modeling within communities
- Sources of PM or other co-pollutants for source-specific spatial exposure assessment (source apportionment)
- Specific pollutants; which metric to measure (e.g. UFP, PM$_1$, PM$_{2.5}$, PM$_{10}$ ...) and how long (to derive long-term exposures)
- Shift to comprehensive uE monitoring and modeling – personal exposure assessment
Exposure assessment: future directions (2)

- Remote sensing of environment (for CH, limited utility for AQ application, generally 10x10km grids, new ones coming 3x3 km)
- Endogenous vs exogenous exposures, urinary metabolites and other biomarkers of specific air pollutant exposures (Exposome)
- Integrating commute exposures assessment
- Innovative sensor-based “community monitoring”
- Database management: handling large volume of poorly specified data (will need intelligent algorithm development)
- Nanoparticles exposures (environmental as well as occupational)
- Strengthening collaborations and multidisciplinarity
Air Pollution Data by Country

Urban population weighted average PM10 concentrations (micro grams per cubic meter) in

Source: The World Bank, 2000

<table>
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<tr>
<th>iso3</th>
<th>country</th>
<th>GDP/capita (in USD)*</th>
<th>PM10 conc. 1999</th>
<th>PM10 conc. 2000</th>
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* Source: CIA World Factbook, 2011

** Urban population consists of all residents living in cities larger than 100,000 and national capitals.