Swiss TPH
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Department of Epidemiology & Public Health

General Principles of and Examples of Environmental Exposure Assessment

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Outline

First half

- Definition of exposure
- Different exposure pathways
- Exposure misclassification
- Air pollution

Second half

- Examples of air pollution exposure assessment in studies
- Use of satellite data
- Other studies

What is exposure?

National Research Council: an event consisting of contact at a boundary between a human and the environment at a specific contaminant concentration for a specified interval of time.

Ott: the existence of a person and an agent (contaminant) in the same microenvironment at the same time (in potential contact with each other).

Jaycock: the product of (concentration), (time), and (duration), or rate of transport of toxicant (mg/cm^2-min)

Human Health Effects of Pollution

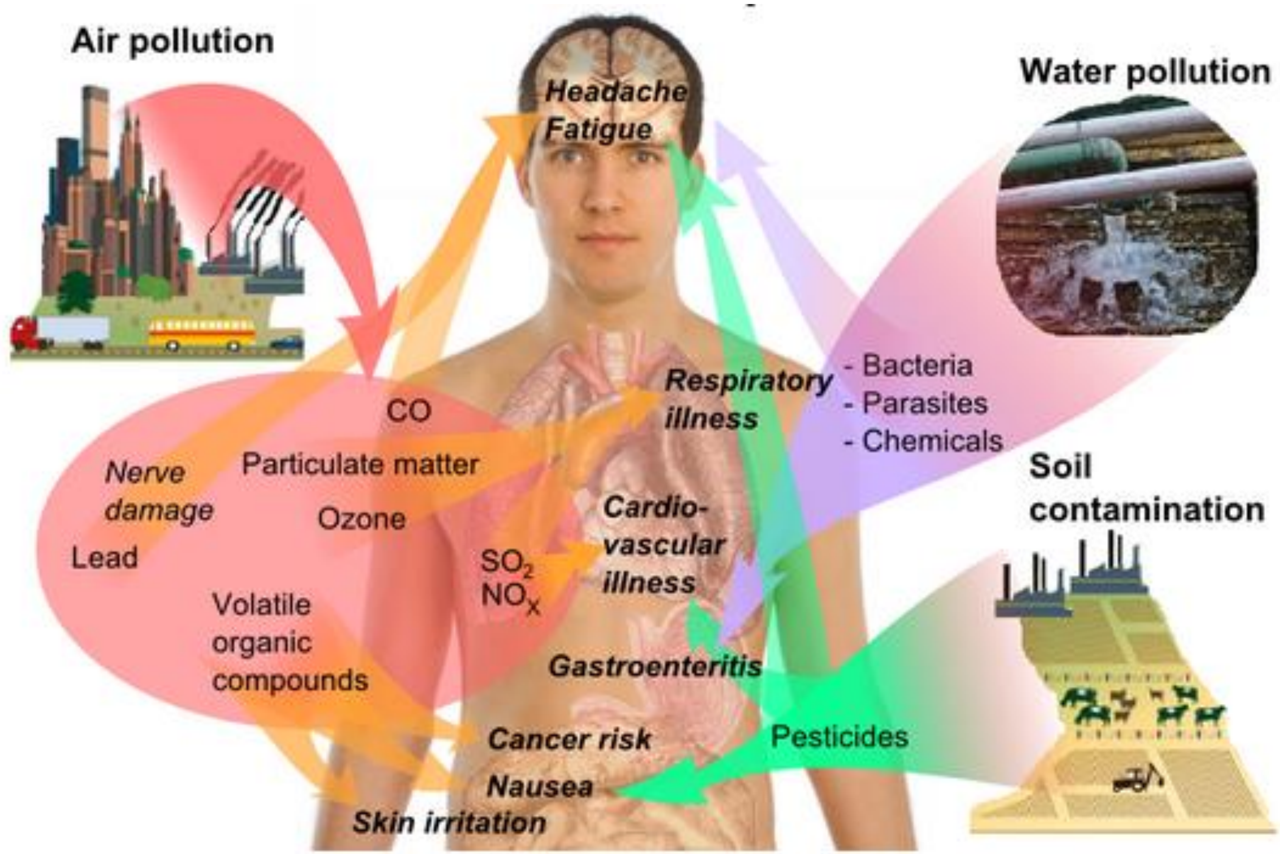

Figure 2: Human Health Effects of Environmental Pollution from Pollution Source to Receptor
Figure shows the human health effects of environmental pollution from pollution source to receptor. *Source: Mikael Häggström via* Wikimedia Commons

Exposure processes

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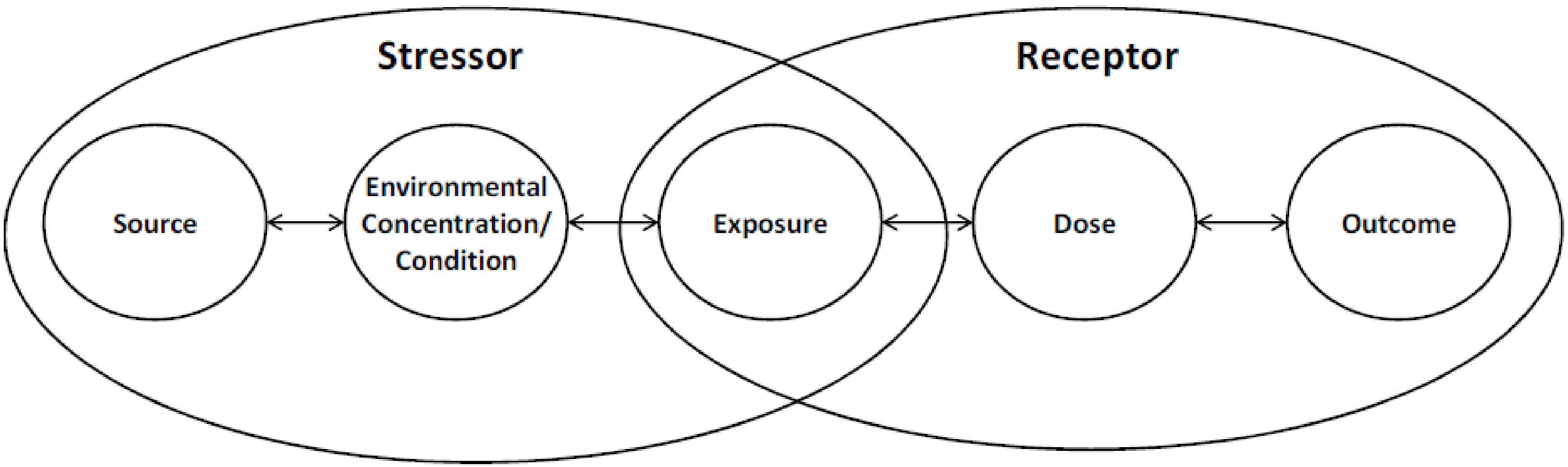
- ***Ingestion*** of contaminants in groundwater, surface water, soil, and food.
- ***Inhalation*** of contaminants in air (dust, vapor, gases), including those volatilized or otherwise emitted from groundwater, surface water, and soil.
- ***Dermal contact*** with contaminants in water, soil, air, food, and other media, such as exposed wastes or other contaminated material.
- ***External exposure*** to radiation.

Environment - Health



Source: Exposure Science in the 21st Century – National Academy of Sciences, 2012

How can we assess exposure?

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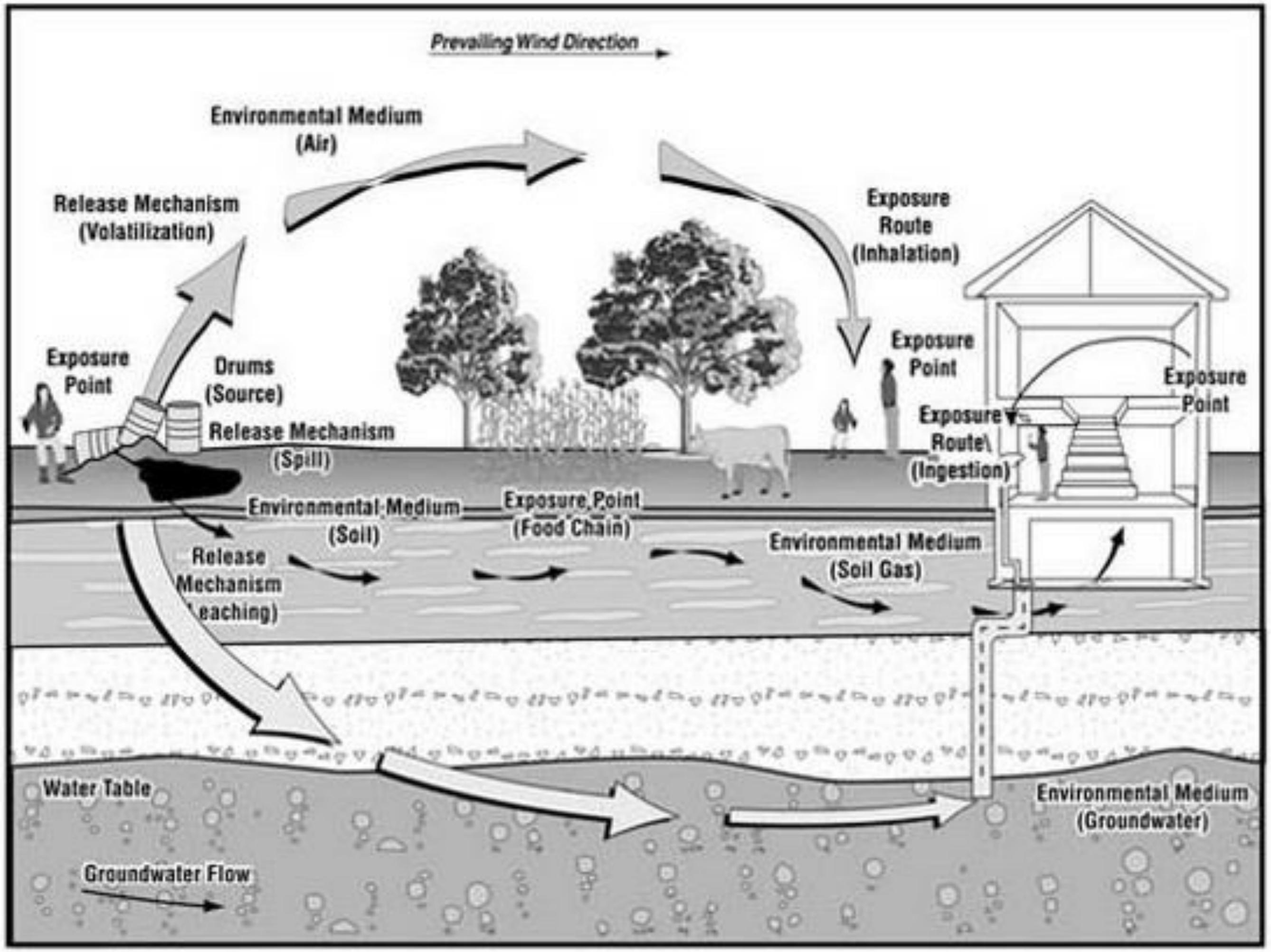
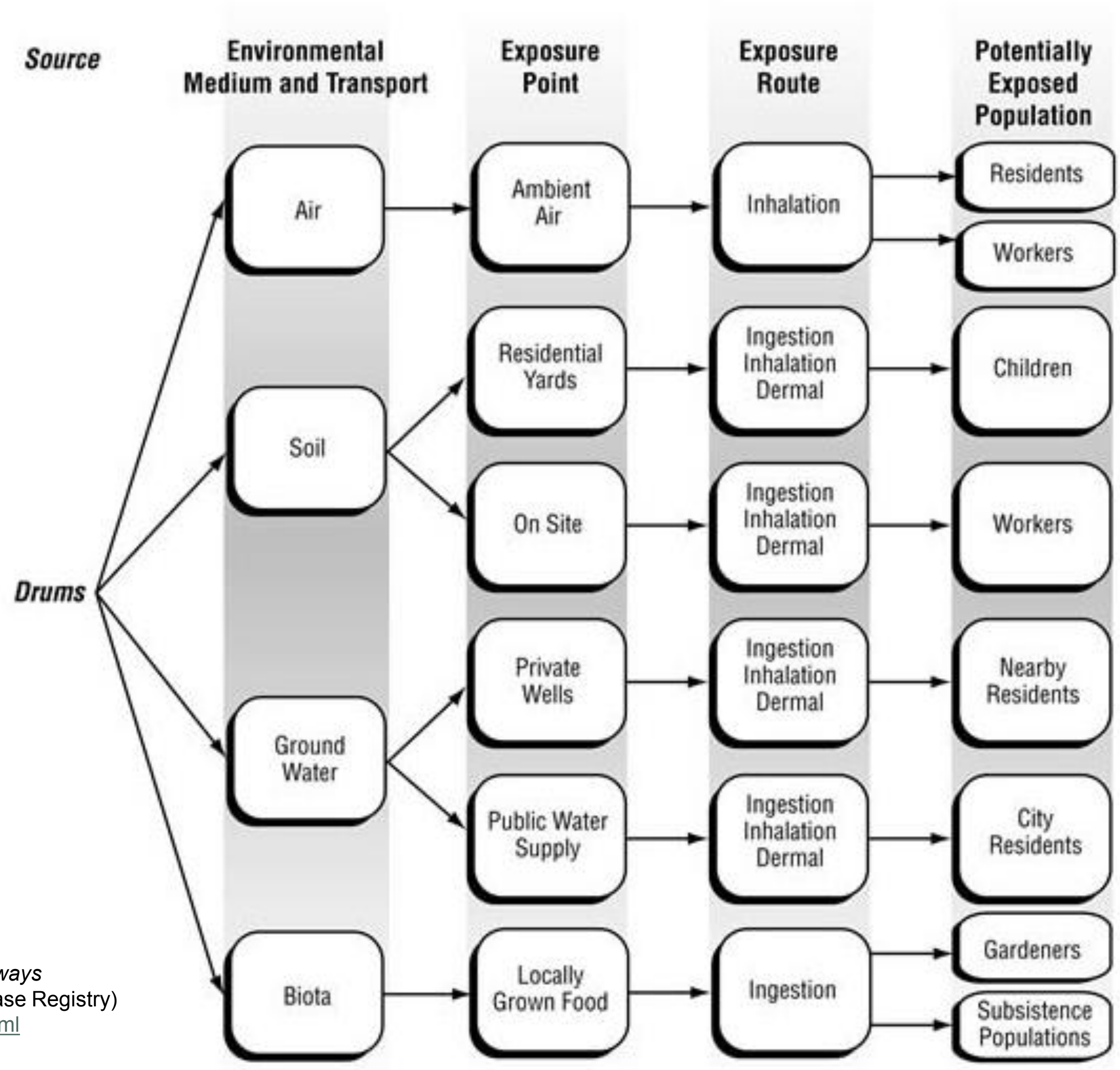
Measurements	Biomonitoring	Individuals	high
Measurements	Exposure monitoring e.g. personal monitoring	Individuals	
Microenvironment modelling	Exposure modelling e.g. probabilistic, time-activity modelling	Individuals, subpopulations	
Regional modelling	Concentration modelling e.g. geostatistic, dispersion or regression model	Subpopulations, populations	metrics precision
Indicator	Source indicator e.g. proximity, source activity	Subpopulations, populations	
Measurements	Concentration monitoring e.g. site measurements, area averaged measurements	Subpopulations, populations	
Questionnaires & diaries	Categorised exposure	Individuals, subpopulation	low

Exposure pathways contaminated site



Source:
Public Health Assessment Guidance Manual
Exposure Evaluation: Evaluating Exposure Pathways
ATSDR (Agency for Toxic Substances and Disease Registry)
http://www.atsdr.cdc.gov/hac/PHAManual/ch6.html

Exposure pathways contaminated site



Source:
Public Health Assessment Guidance Manual
Exposure Evaluation: Evaluating Exposure Pathways
ATSDR (Agency for Toxic Substances and Disease Registry)
http://www.atsdr.cdc.gov/hac/PHAManual/ch6.html

Calculating Exposure Doses

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Exhibit 3. Water Ingestion Exposure Dose Equation

Exposure doses from ingestion of water can be calculated as follows:

D = (C x IR x EF) / BW

where,

D = exposure dose (mg/kg/day)
C = contaminant concentration
IR = intake rate of contaminated
EF = exposure factor (unitless)
BW = body weight (kg)

Exhibit 4. Water De

Doses from dermal contact with water c

D = (C x P x SA x ET x CF) / BW

where,

D = dose (mg/kg/day)
C = contaminant concentration (mg
P = permeability coefficient (cm/h
SA = exposed body surface area (cm
ET = exposure time (hours/day)
CF = conversion factor (1 L/1,000 c
BW = body weight (kg)

Exhib

Exposure doses from inge

D = (C x IR x EF x CF) / BW

where,

D = exposure dose (mg/kg/day)
C = contaminant concentration (mg/kg)
IR = intake rate of contaminated soil (mg/day)
EF = exposure factor (unitless)
CF = conversion factor (10^{-6} kg/mg)
BW = body weight (kg)

Default
100 mg/day -
200 mg/day -
5,000 mg/day

Note:
mg/day - mill

Exposure doses

D = (C x

where,

D = expo
C = cont
IR = intal
EF = expo
BW = body

Standard Default Values

Body Weight (BW):

70 kg - adult, approximate average
16 kg - children 1 through 6 years old, 50th percentile
10 kg - infant (6 to 11 months) approximate average

Exposure Duration (ED):

70 yrs - lifetime; by convention
30 yrs - national upper-bound time (90th percentile) at one residence
9 yrs - national median time (50th percentile) at one residence
6 yrs - children 1 through 6 years old

Note:
kg - kilogram
yrs - years

Exhibit 8. Fish Ingestion Exposure Dose Equation

doses from ingestion of fish can be calculated as follows:

x CF) / BW

Rates
ulation (all fish)
average
fishers (freshwater
ercentile nationwide
fishers (marine
ercentile for Gulf
fishers (all fish),
ile nationwide

Intake Rates
ate mean)
nt, less than 1 year
l, 6–8 years
12–14 years
12–14 years
le, 19–65+ years
, 19–65+ years

tion

follows:

exposure dose (mg/kg/day);
contaminant concentration (mg/g);
consumption rate of food group (g/day);
exposure factor (unitless);
body weight (kg);
total number of food groups.

doses from ingestion of homegrown food is calculated similarly:

$D = \sum_{i=1}^{n} (CL \times CRi \times EF \times PHi) / BW$

percentage of food that is homegrown.

Source:
Public Health Assessment Guidance Manual
Exposure Evaluation: Evaluating Exposure Pathways
ATSDR (Agency for Toxic Substances and Disease Registry)
http://www.atsdr.cdc.gov/hac/PHAManual/ch6.html

Example – Exposure through Soil ingestion

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Exhibit 5. Soil Ingestion Exposure Dose Equation

Exposure doses from ingestion of soil can be calculated as follows:

$$D = (C \times IR \times EF \times CF) / BW$$

where,

D	=	exposure dose (mg/kg/day)
C	=	contaminant concentration (mg/kg)
IR	=	intake rate of contaminated soil (mg/day)
EF	=	exposure factor (unitless)
CF	=	conversion factor (10^{-6} kg/mg)
BW	=	body weight (kg)

Default Soil Intake Rates

100 mg/day -	adult, average soil ingestion rate
200 mg/day -	child, average soil ingestion rate
5,000 mg/day -	pica child, average soil ingestion rate *(to be used when assessing acute exposure situations only)*

Note:
mg/day - milligrams per day

Source:
Public Health Assessment Guidance Manual
Exposure Evaluation: Evaluating Exposure Pathways
ATSDR (Agency for Toxic Substances and Disease Registry)
http://www.atsdr.cdc.gov/hac/PHAManual/ch6.html

Exposure modelling

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- Interpolation
  - Models spatial pattern of exposure on the basis of monitored (georeferenced) data with or without covariates

    e.g. kriging in soil pollution or inverse distance weighting in air pollution exposure modelling

- Source-receptor modelling
  - Models exposure by simulating relationships between source and receptor

    e.g. dispersion modelling in air pollution exposure modelling

What makes a good exposure measure?

- Specific
- Accurate
- Robust
- Flexible
- Representative
- Practical

Exposure misclassification

Models are a simplified representation of reality:

- Every model makes assumptions and generalisation about processes, interactions and feedbacks in the reality it describes
- Exposure models make assumption about spatial patterns of environmental hazard concentrations and the individual or population under study
- Various aspects of uncertainty associated with each method of estimating exposure

Air pollution

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”**Air pollution** is contamination of the indoor or outdoor environment by any chemical, physical or biological agent that modifies the natural characteristics of the atmosphere.” *Definition according to WHO*

Primary pollutants → **Secondary pollutants**

+ O_2 + ☀




Nitrogen oxides (NO_x)

Particulate Matter (PM)

Carbon monoxide (CO)

Sulfur oxides (SO_x)

Volatile organic compounds (VOC)

Ozone (O_3)

«Smog»

Peroxyacetylnitrat (PAN)

Where does it come from?

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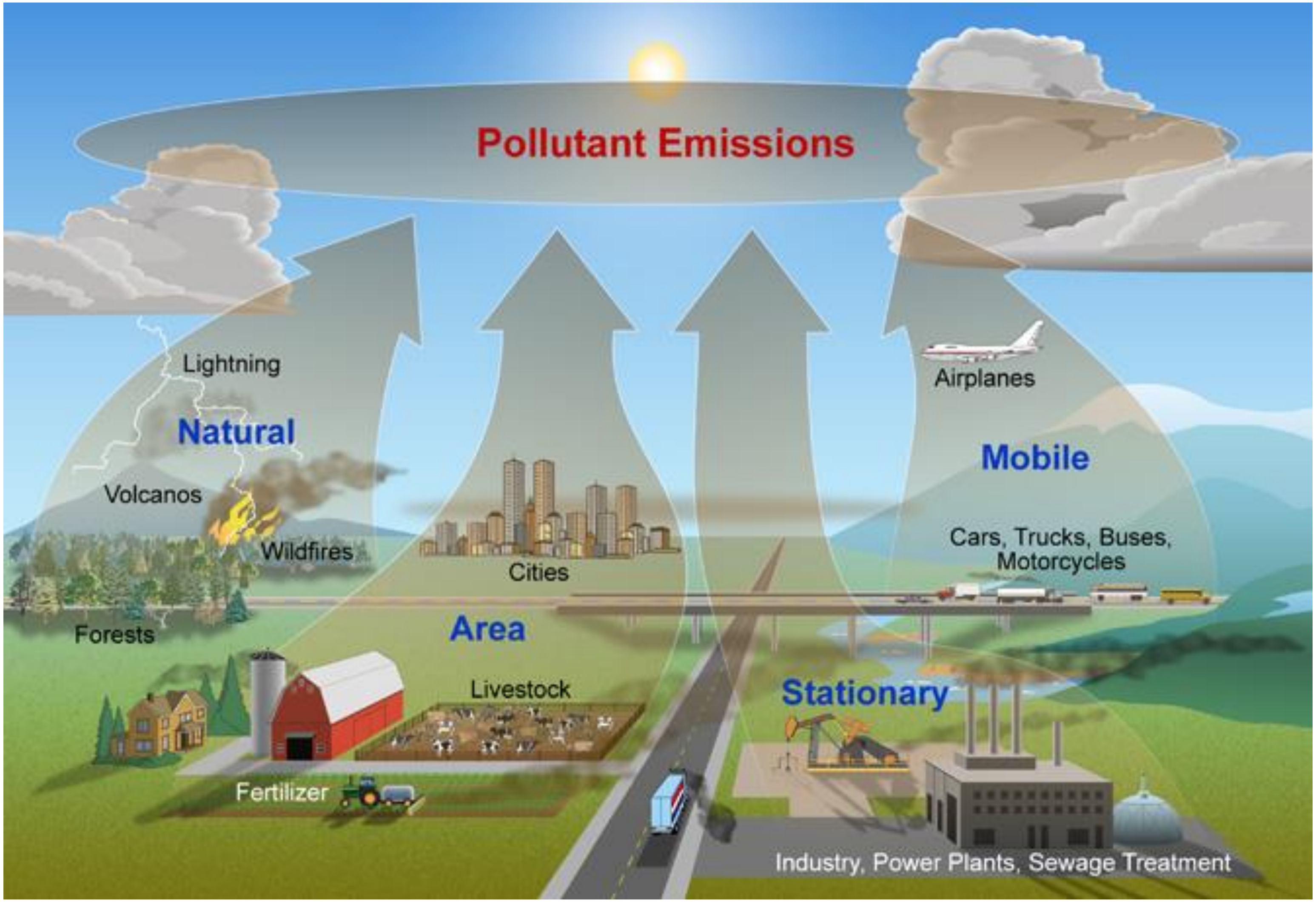

Sources of particulate air pollution

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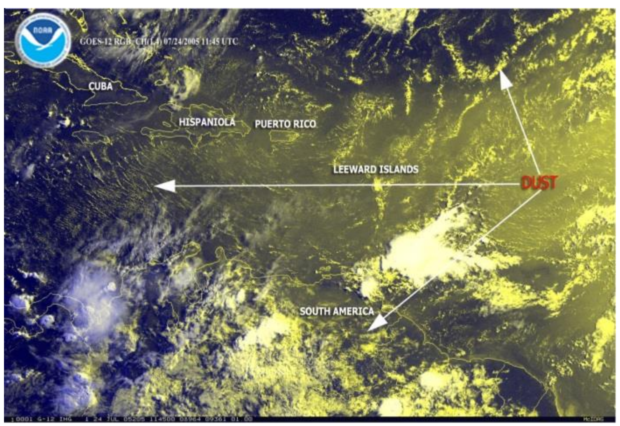
Natural



Long distance transport!

Anthropogenic





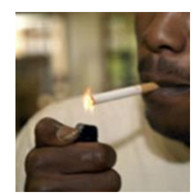




⇒ **Combustion**
⇒ **Abrasion**

Indoor sources



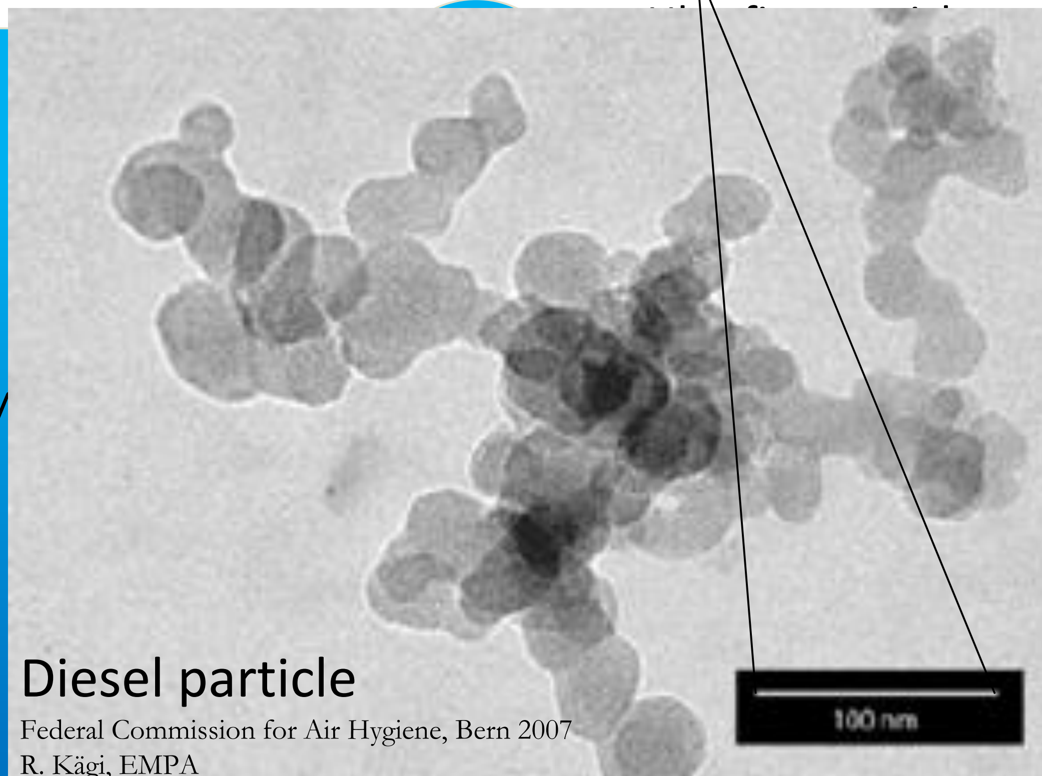



Particulate Matter (PM)

PM size fractions:

PM

= 1000 µm



Diesel particle
Federal Commission for Air Hygiene, Bern 2007
R. Kägi, EMPA

< 0.1 µm → Ultrafine particle (UFP)

½ diameter of a human hair (50 µm)

How can we measure air pollution?

Health effects

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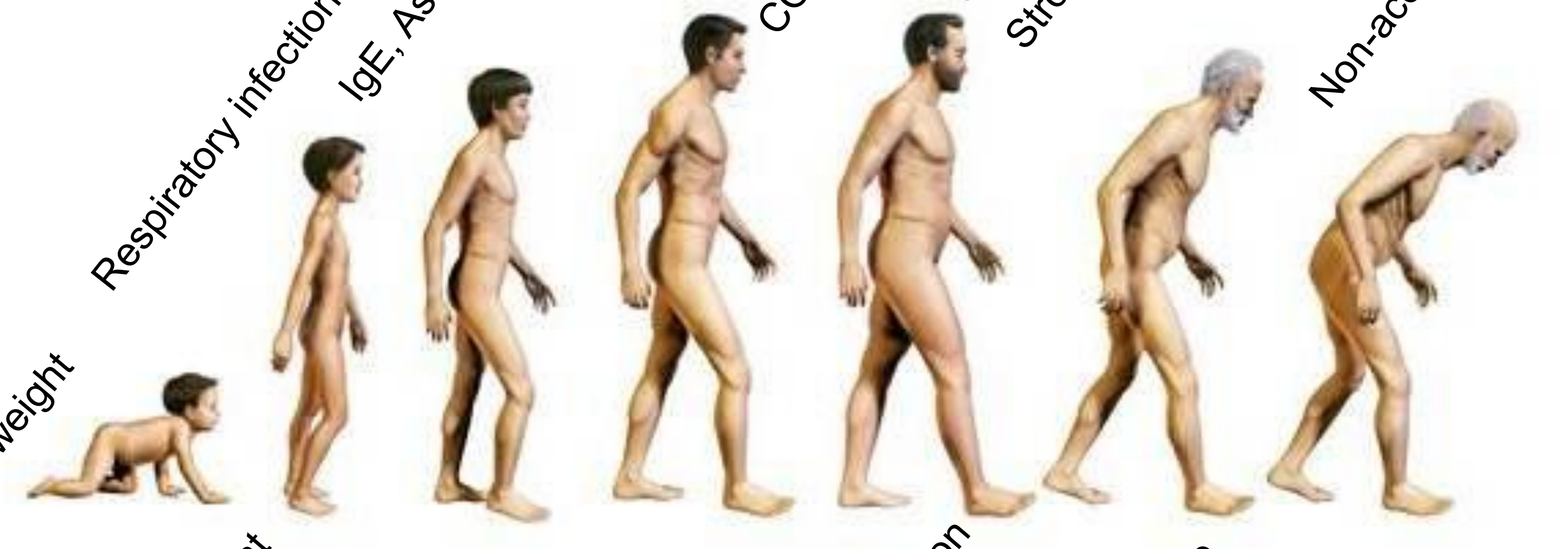

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Who is affected by air pollution?

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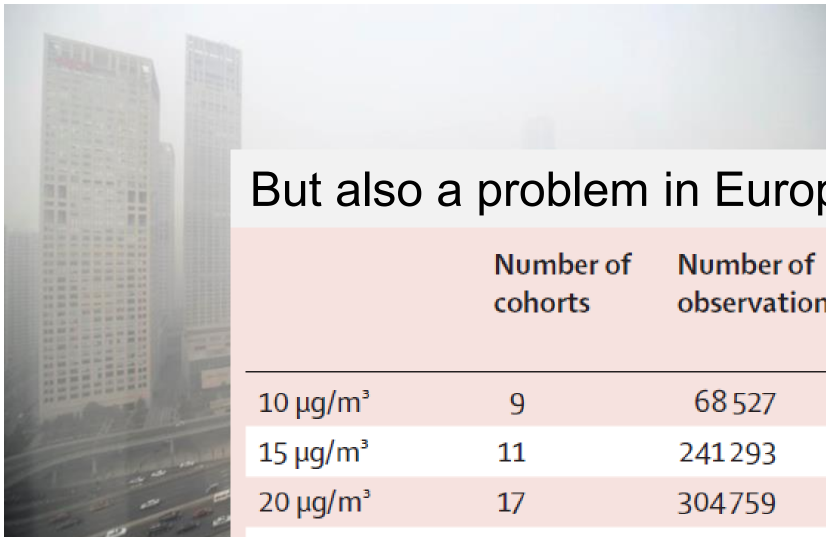
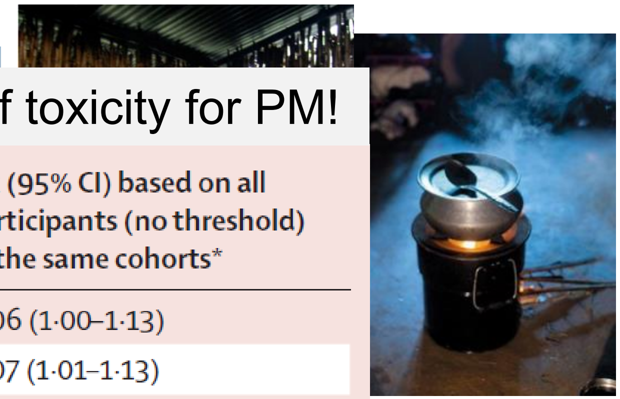
Big problem in mega cities



Beijing, Janu
$PM_{2.5}$ > 500

Big problem in middle and low income countries

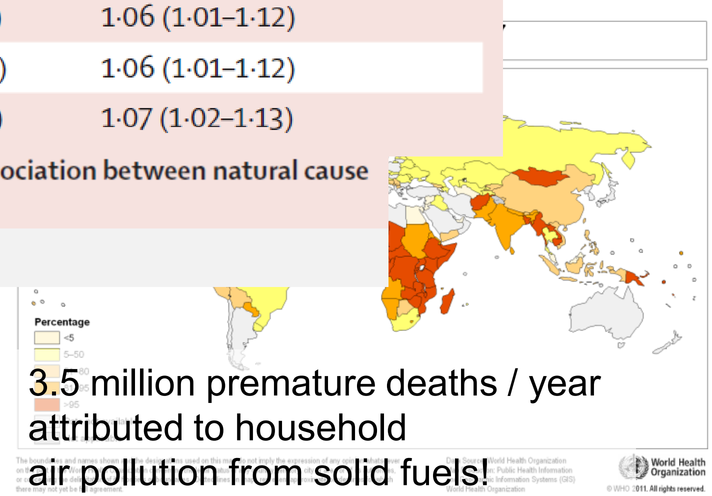


But also a problem in Europe - no threshold of toxicity for PM!

	Number of cohorts	Number of observations	HR (95% CI)	HR (95% CI) based on all participants (no threshold) in the same cohorts*
10 μg/m³	9	68 527	1·02 (0·87–1·19)	1·06 (1·00–1·13)
15 μg/m³	11	241 293	1·04 (0·98–1·11)	1·07 (1·01–1·13)
20 μg/m³	17	304 759	1·07 (1·01–1·13)	1·06 (1·01–1·12)
25 μg/m³	17	309 310	1·06 (1·00–1·12)	1·06 (1·01–1·12)
No threshold	19 (all)	322 159	1·07 (1·02–1·13)	1·07 (1·02–1·13)

Table 5: Results from random-effects meta-analyses for the adjusted association between natural cause mortality and exposure to $PM_{2.5}$ below various threshold values

Beelen et al. 2013



3.5 million premature deaths / year attributed to household air pollution from solid fuels!

IHME, GBD 2010 **WHO, 2011**

WHO guidelines for $PM_{2.5}$
annual mean: 10 μg/m_3
24-hour mean: 25 μg/m_3

Where are we exposed?

And where do we measure?

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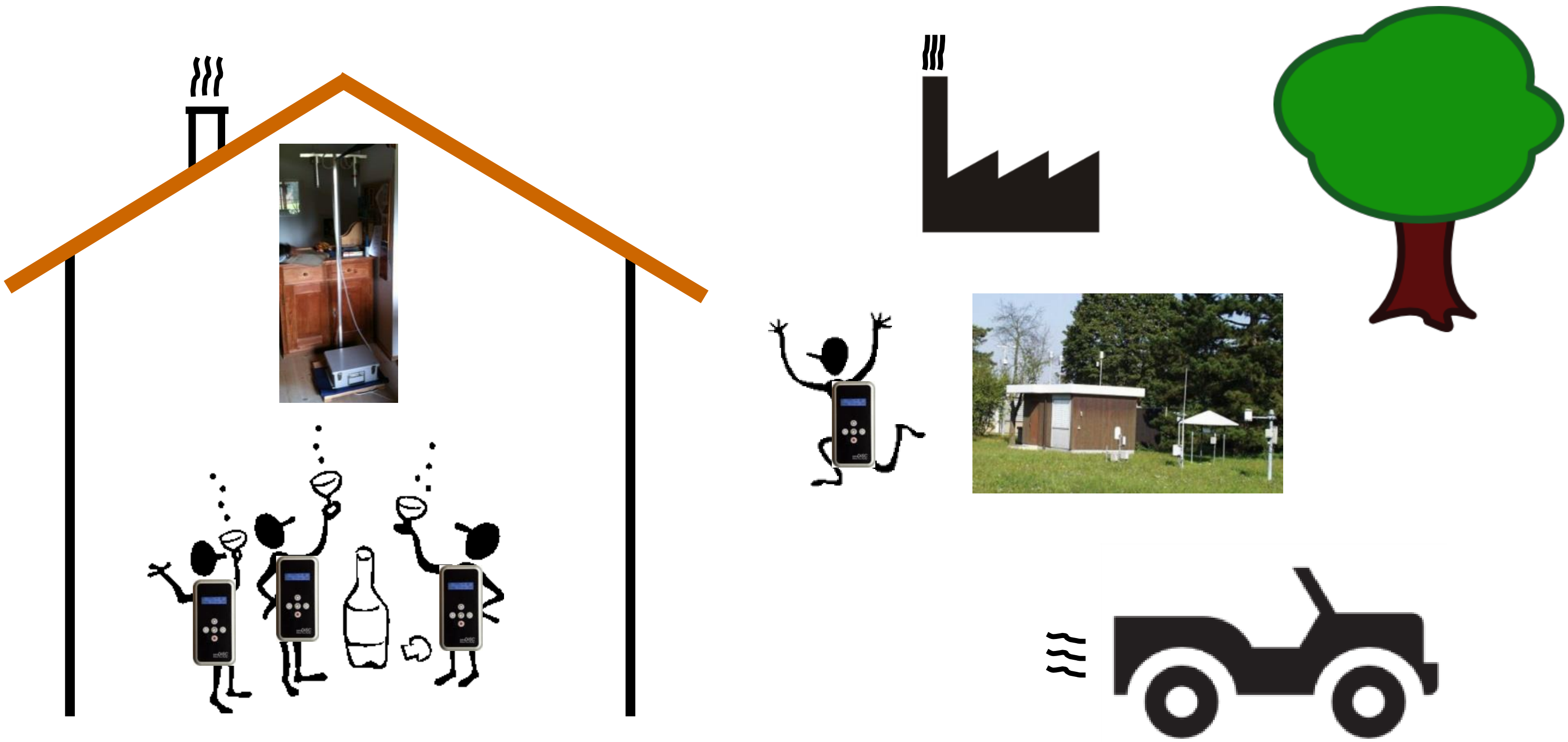

- We spend majority of time indoors
- New buildings => better insulation to save energy

Where do we monitor air pollution

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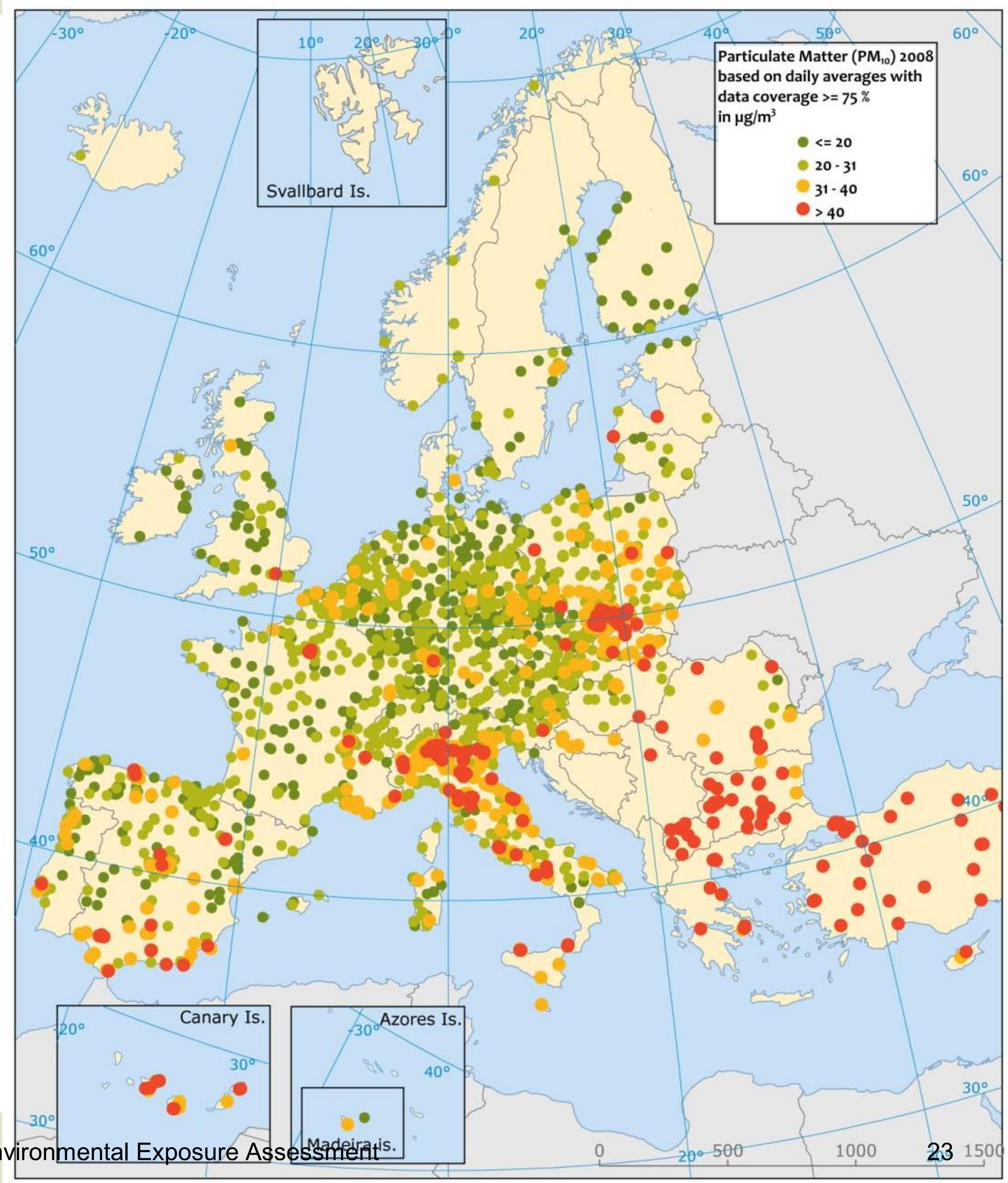
Annual mean PM_{10} concentrations in Europe in 2008



What can measurements tell us

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Figure 1 - Annual mean NO_2 at 'worst 20' EEA monitors (2010)[1]

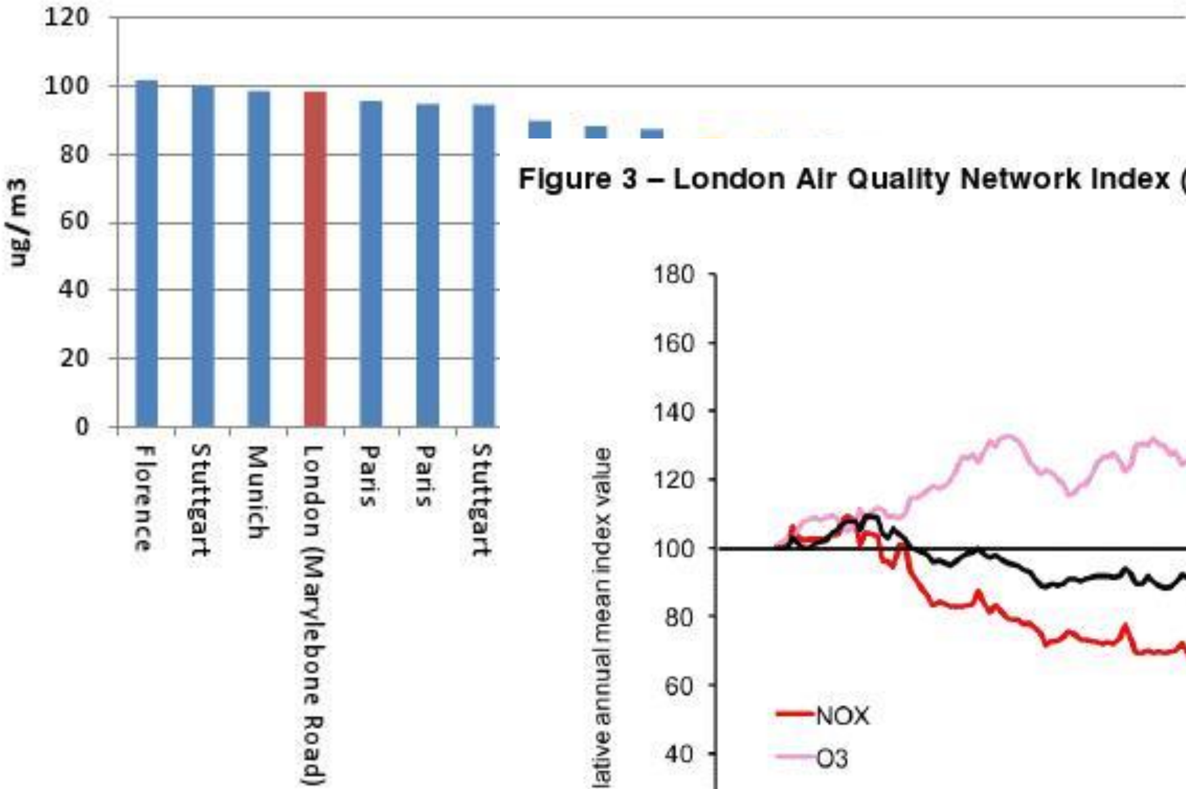

Figure 3 – London Air Quality Network Index (Average) for NO_2, NO_x and O_3 [3]

Environmental modelling:
Modelled NO2 concentration: 3-day simulation over Europe

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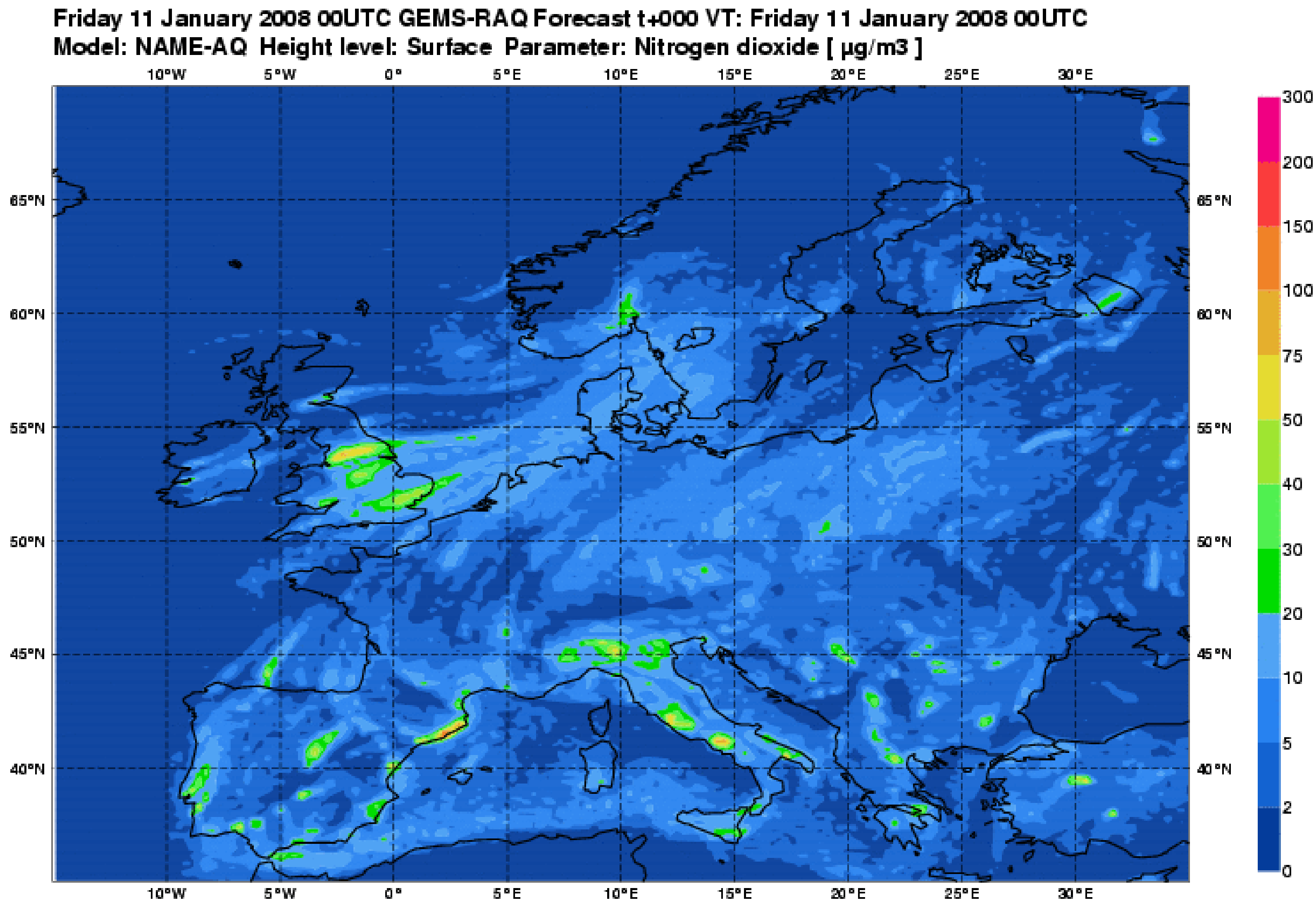

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…..and across the world

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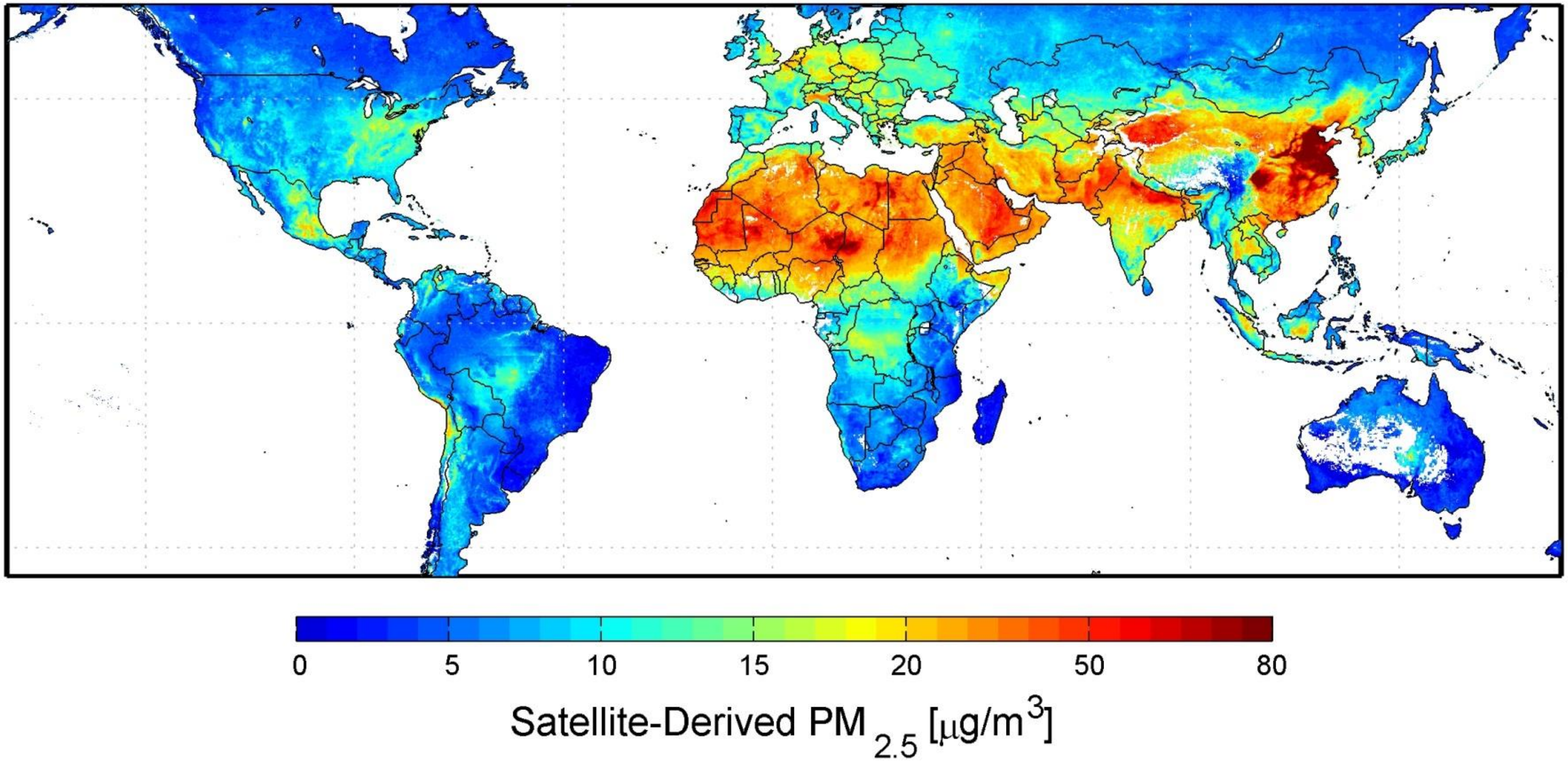


- Donkelaar et al, 2010

Methods

- Proximity based methods
- Spatial interpolation
- Dispersion modelling
- Land Use regression

Tobler's first law of geography:

Everything is related to everything else

...but near things are more related than distant things

Modelling methods for point data

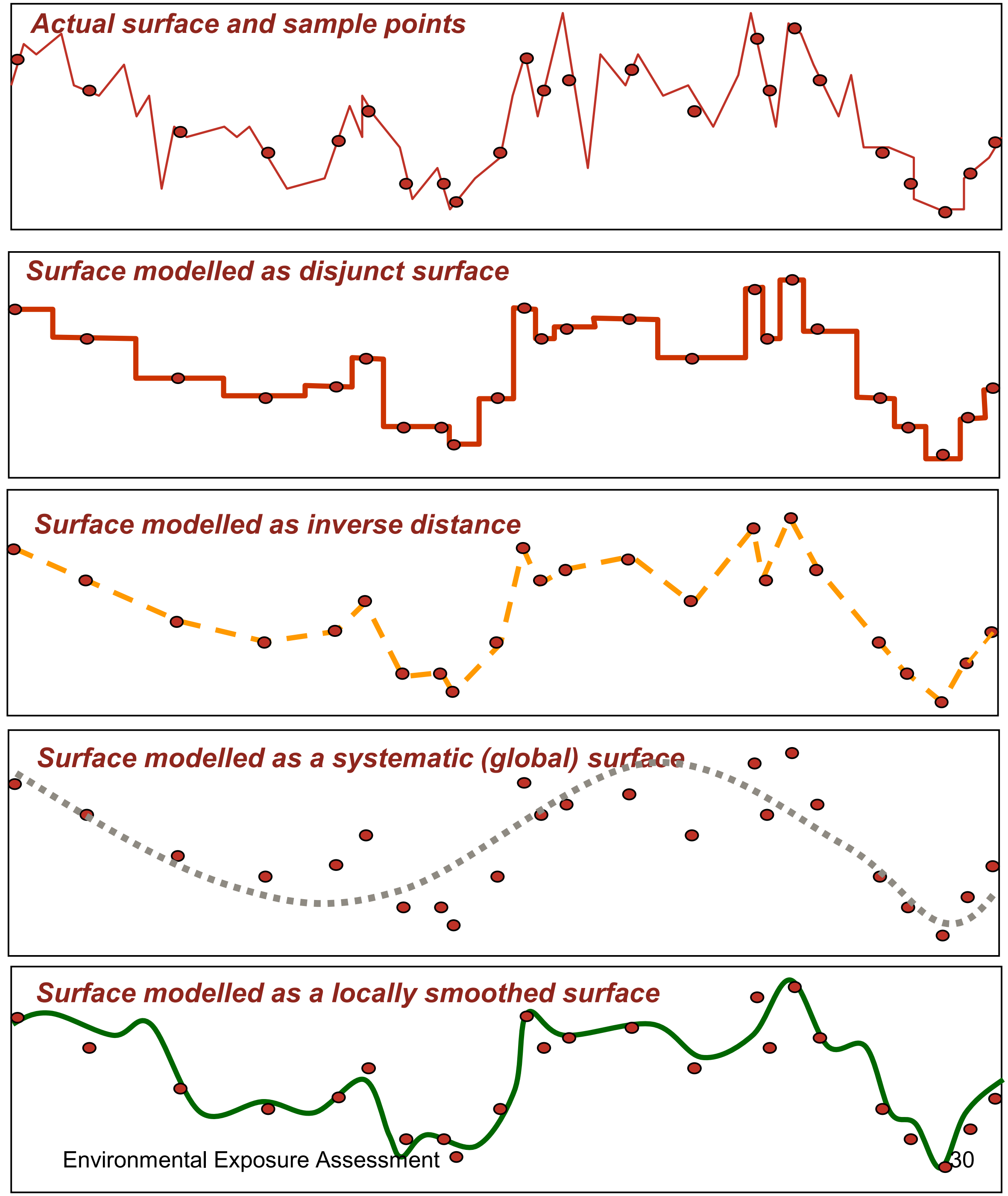
Approach	*Example*	*Description*
Proximity	Voronoi tesselation	Creates areas around each point containing locations nearest to that point
	Buffering	Creates zone (buffer) of specified distance around point
Distance functions	Inverse-distance weighting	Weights each location in terms of inverse distance from monitoring site
Global interpolators	Trend surface analysis	Fits global surface through data points
Local interpolators	Kriging	Fits series of local surfaces through data points

Interpolation

- Trend surface analysis
- Inverse distance weighting
- Spline
- Local polynomials
- Kriging

Which method is the most appropriate?

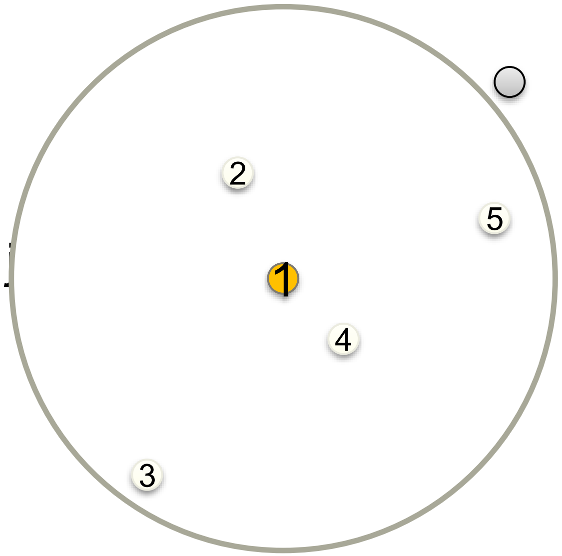
- Informed by good understanding of the data
- Validate with another dataset
- Measure of the certainty or accuracy of the predictions



Values at unsampled locations are a function of values at sampled locations within a specified zone of influence (e.g. radius). The weighting (or influence) of surrounding locations are usually a function of inverse distance.

$$Z_j = \sum_i \lambda_i Z_i$$

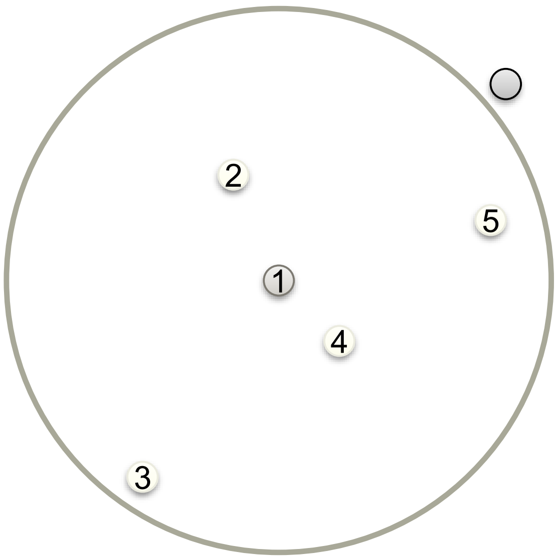
Z_j is the value (we are trying to predict) at location j
λ_i is the weighting for location i
Z_i is the sampled value at location i



$$\lambda_i = 1/d_i^p \Big/ \sum_{i=1}^{N} 1/d_i^p$$

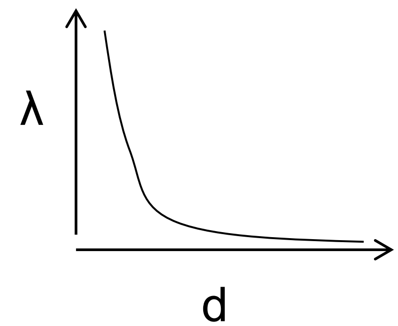
d_i is the distance between prediction location j and each measured location i
P is the power function for distance (typically ‘2’)

Inverse distance weighting



$$\sum_{i=1}^{N} \lambda_i = 1$$

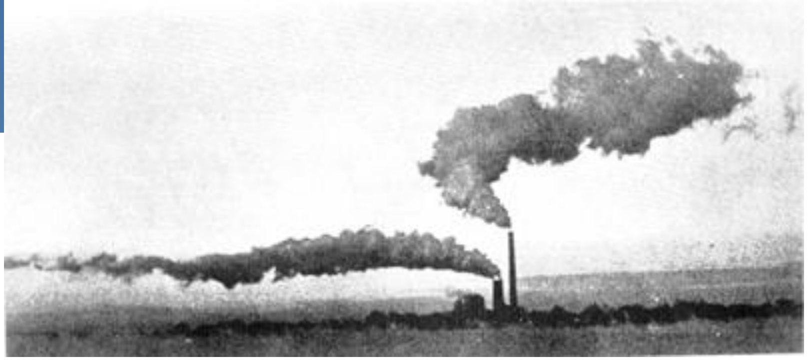
Weights always sum to 1



ID	X	Y	Zi	d	d²	1/d²	weight	% cont.	Zj
2	2	6	10	2.24	5	0.20	0.24	23.93	2.39
3	1	1	5	3.61	13	0.08	0.09	9.20	0.46
4	4	3	20	1.41	2	0.50	0.60	59.83	5.98
5	7	5	10	4.12	17	0.06	0.07	7.04	1.47
							1		**10.24**

Dispersion modelling




Atmospheric dispersion models

- (mostly) use Gaussian equations to model the transport of gaseous pollutants through the atmosphere and predict ground level concentrations.
- originally developed as a tool for regulatory compliance modelling and traditionally used in environmental impact assessment.
- require detailed input data on emissions (for industrial sources: stack height, stack diameter, emission rate, temperature of exit gas; for traffic: flow, composition, speed)
- meteorological parameters (a minimum of wind direction, wind speed, ambient temperature, cloud cover).

Modelling air pollution

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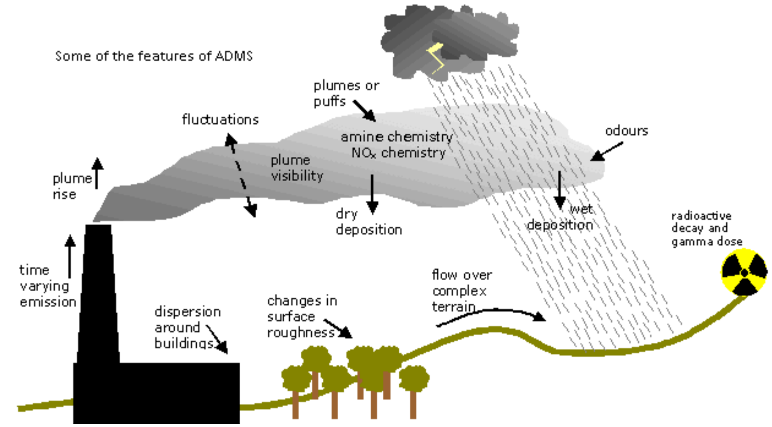
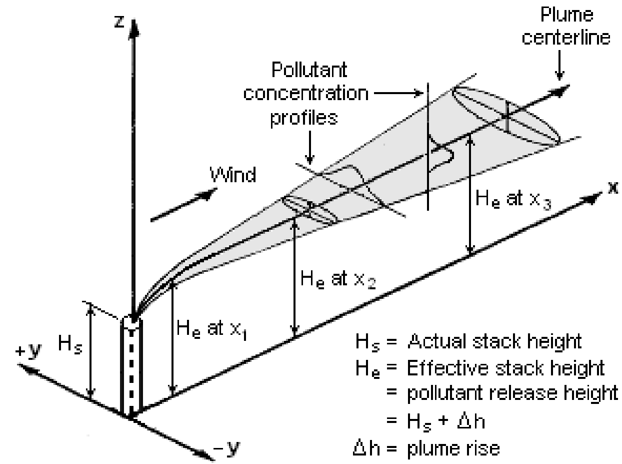
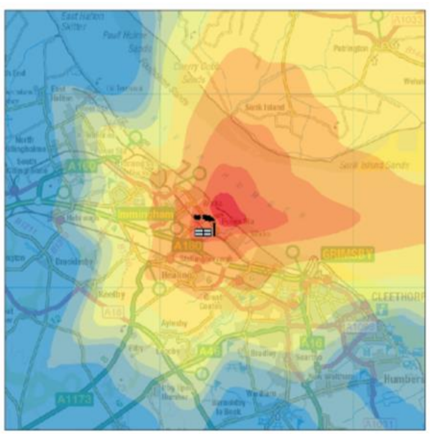


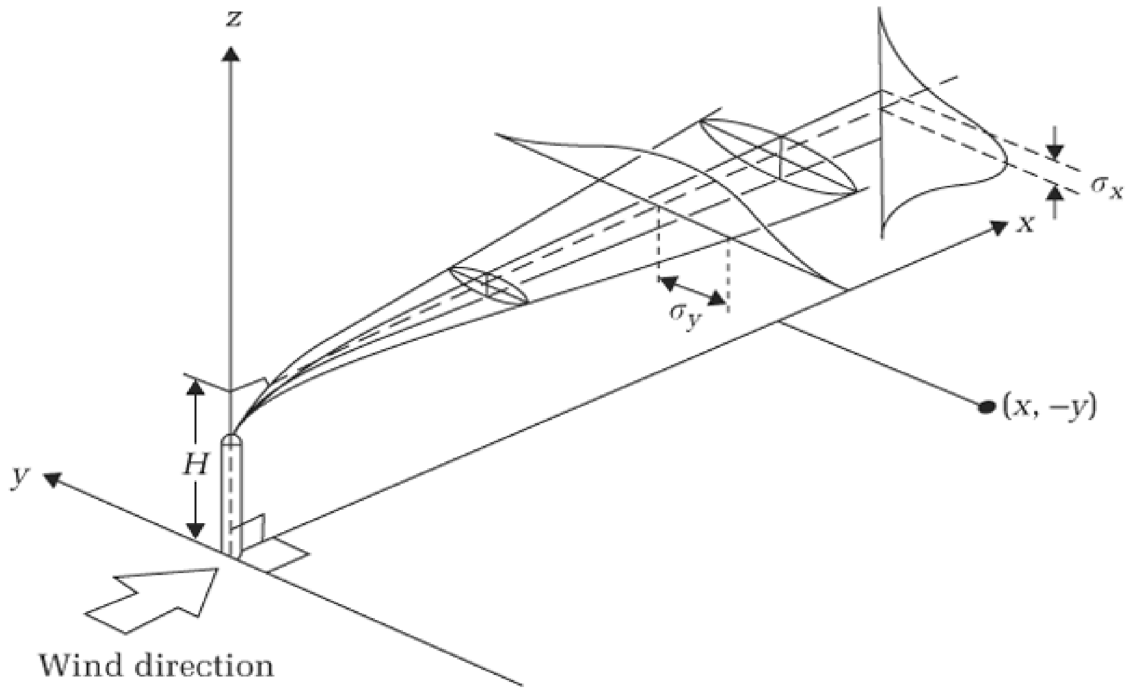




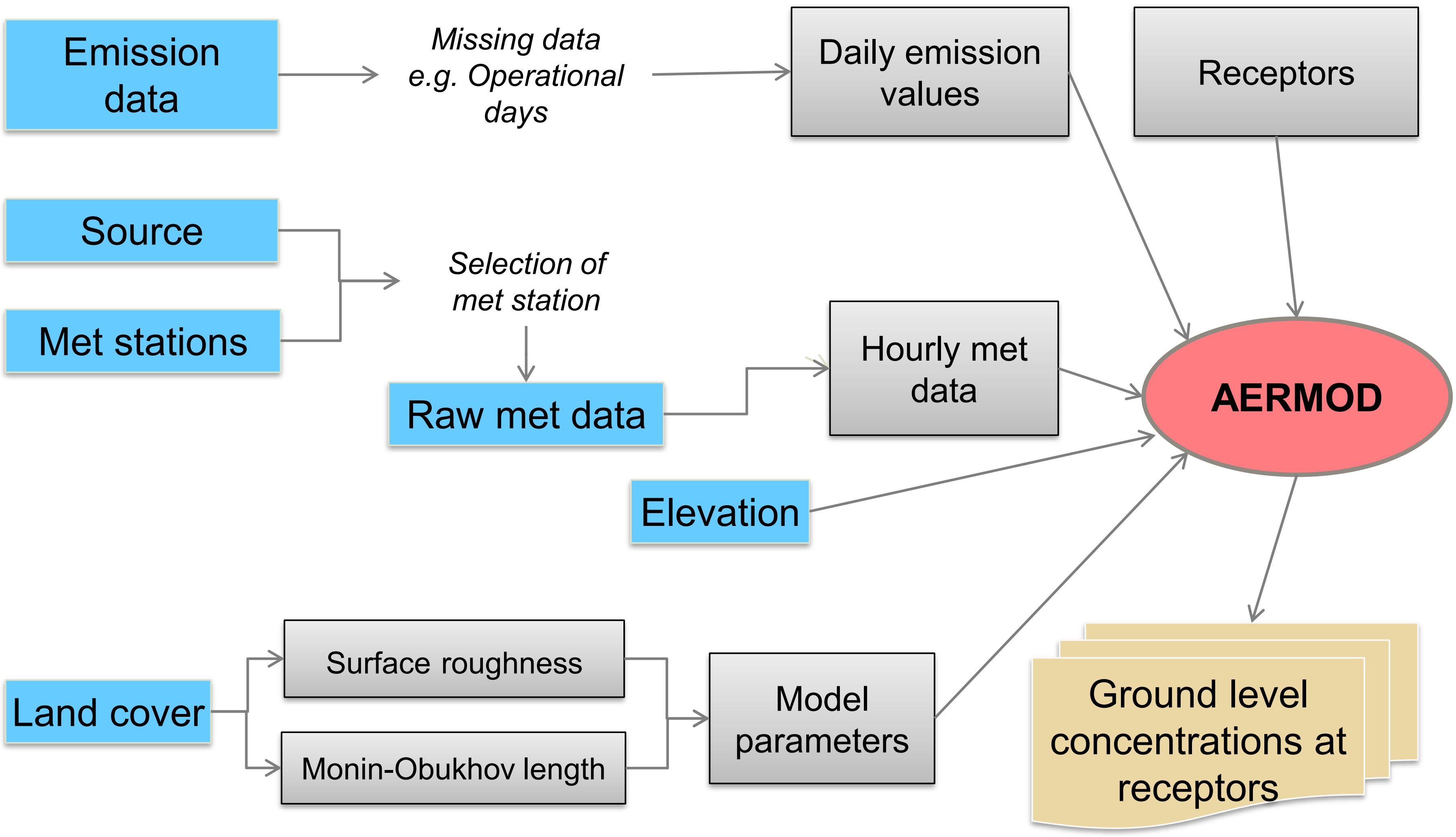
Gaussian plume distribution

$$x = \frac{Q}{2\pi\bar{u}\sigma_y\sigma_z} exp\left(-\frac{y^2}{2\sigma_y^2}\right) \times \left[exp\left(-\frac{(z-H)^2}{2\sigma_z^2}\right) + exp\left(-\frac{(z+H)^2}{2\sigma_z^2}\right)\right]$$

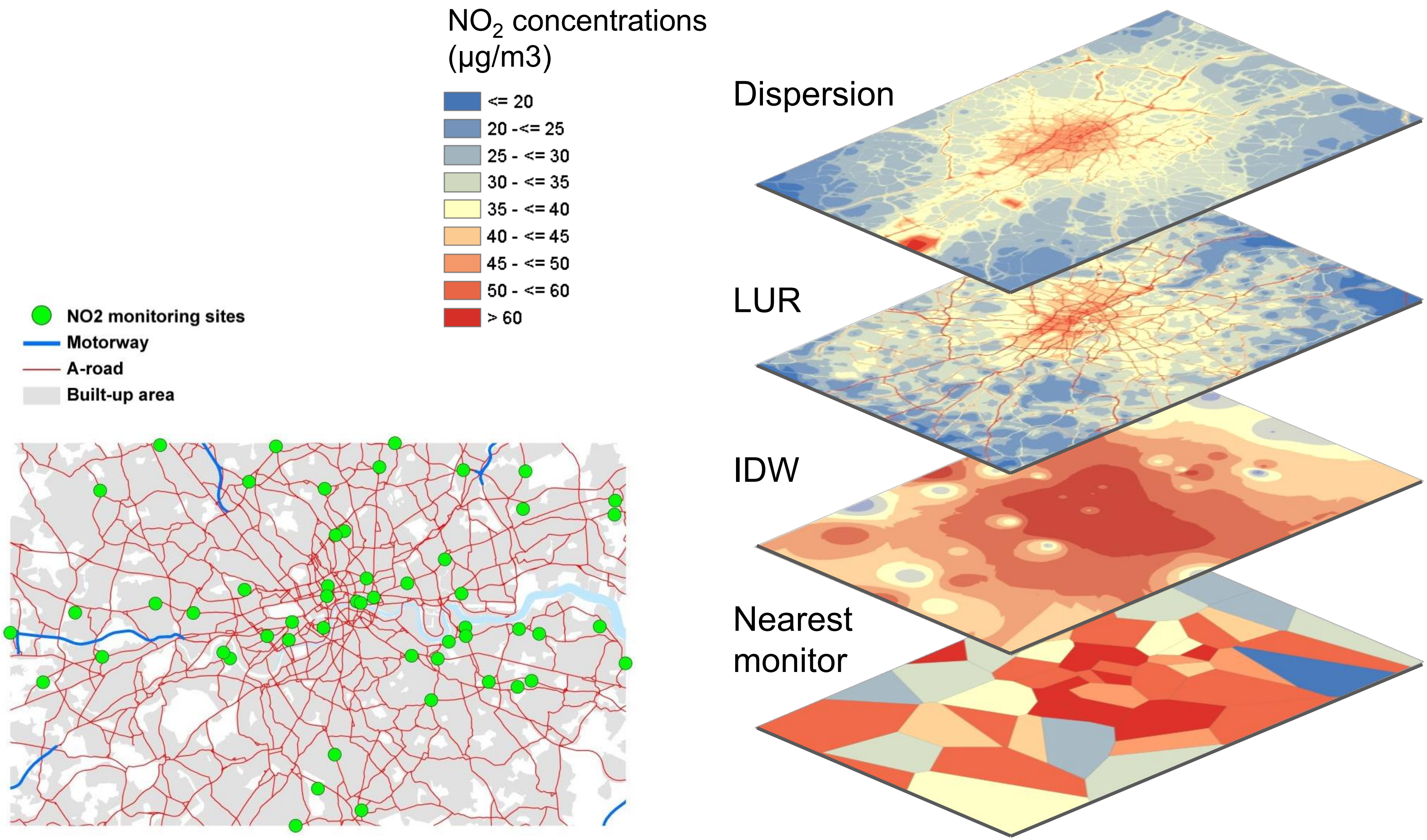
Q = pollutant mass emissions rate (μgs−1),
ū = wind speed (in m s−1),
x, y, and z = along wind, crosswind, and vertical distances (in m)
H = effective stack height (the height of the stack + the plume rise (in m)).
σ_y and σ_z = extent of plume growth, and are the standard deviations of the horizontal and vertical concentrations in the plume (in m) – depending on atmospheric conditions



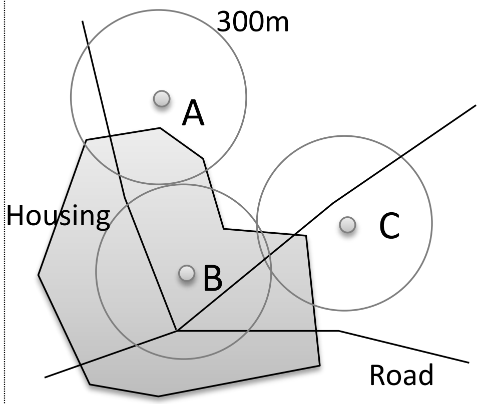
Typical flow chart dispersion modelling



Air pollution modelling approaches



Land Use Regression (LUR)



NO_2 measurement sites (A,B,C)

	Measured NO_2	$Traffic_{300}$	$Housing_{300}$	Altitude
A	37	9,000	20	5
B	48	60,000	50	10
C	30	18,000	10	6

LUR modelling

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- Outcome variables = annual average pollutant concentrations
- Predictor variables:
  - Land use (CORINE)
  - Road length, distance to road (Eurostreets)
  - Population density/household density
  - Altitude, Longitude, Latitude
  - Traffic intensity, distance to road (Local road network)
  - Local variables
- Supervised stepwise forward regression
- Model checks: Cook’s D, Heteroscedasticity of residuals, VIF, spatial autocorrelation (Moran’s I)
- Leave-one-out cross-validation

Example LUR model development

Table 2. Stages of model development for the Thames Valley LUR model (n=40).

Stage	Variable	B	R^2	$Adj.R^2$	Sig. (p)	VIF	SEE
1	(Constant)	30.19	0.671	0.662	0.000	-	10.40
	HEAVYTRAFLOAD50	0.0001500			0.000	1.000	
2	(Constant)	10.8515519	0.837	0.828	0.003	-	7.42
	ROADLENGTH500	0.0016410			0.000	1.120	
	HEAVYTRAFLOAD50	0.0001242			0.000	1.120	
3	(Constant)	9.90	0.864	0.852	0.004	-	6.89
	HLDRES5000	0.0000002			0.011	1.768	
	HEAVYTRAFLOAD50	0.0001204			0.000	1.136	
	ROADLENGTH500	0.0011237			0.001	1.805	

Modelling of long-term air pollution

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- Satellite data is increasingly used to help predict ground level pollutant concentrations.
- At the same time dispersion or Chemical Transport Modelling (CTM) is used in conjunction with land use regression modelled in so-called hybrid models.
- Bring together information from both satellites and dispersion modelling in a European LUR framework for $PM_{2.5}$ and NO_2.

- **Aims**
- To compare the performance of satellite-derived and chemical transport model estimates with local variables in a $PM_{2.5}$ and NO_2 land use regression model.
- To produce $PM_{2.5}$ and NO_2 land use regression models for Western Europe for large scale health studies.

Data

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➢ ***Monitoring data***

- AIRBASE monitoring data (2010) for 2400 sites (NO_2)
- The monitoring data were stratified by study area and site type and the model was derived on 80% and validated on the remaining 20% sites.

➢ ***Predictor data***

- Annual averages inferred from aerosol optical depth ($PM_{2.5}$) and from tropospheric NO_2 columns retrieved from NASA satellites (SAT)
- CTM and NO_2 estimates from the MACC-II Ensemble model.
- Other predictor data (100x100m), calculated for different buffer sizes, included land cover (CORINE), gridded road network, altitude, latitude.
- Restricted to predictor data available for the whole study area

All models – $PM_{2.5}$ and NO_2

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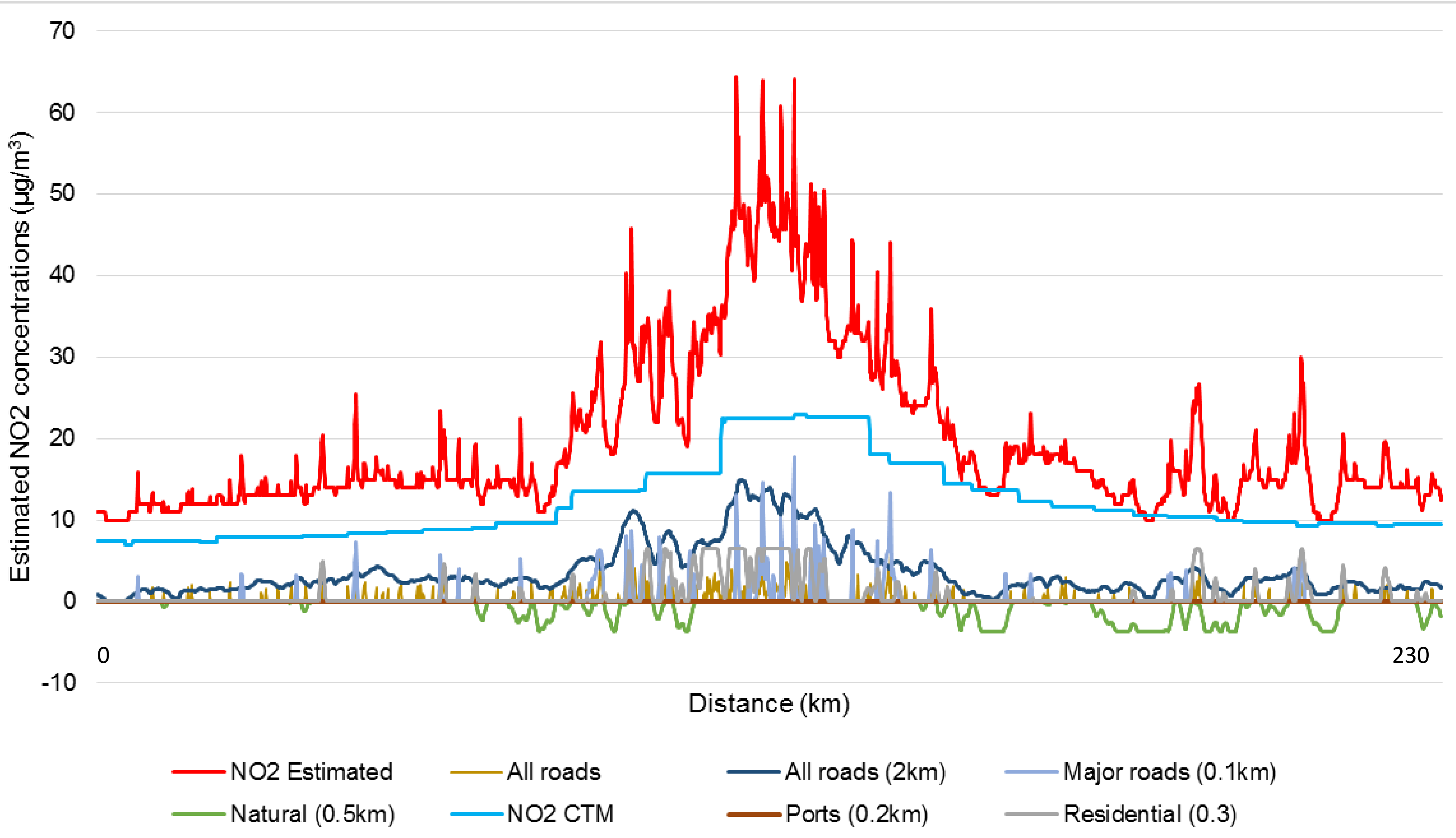
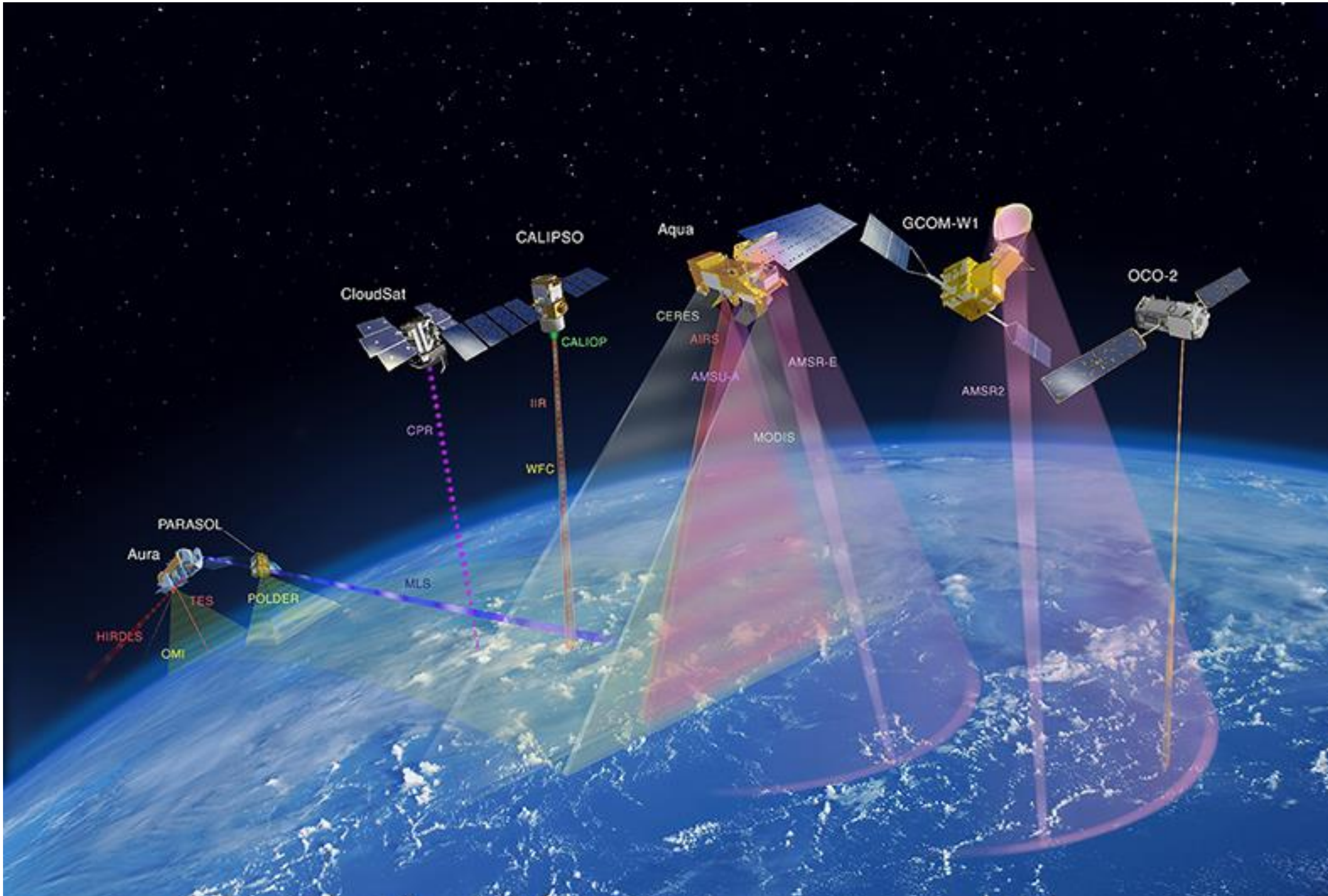
	Model	Predictor variables	Adj-R^2	SEE	HOV R^2	COV R^2
$PM_{2.5}$						
ESCAPE	M1	All roads (0.7km), Urban green (1.8km), Natural (10km), Residential, Major roads (0.1km), Y-coord	0.38	4.4	0.32	0.21
	M2	PM2.5 SAT, All roads (5km), Residential, Altitude, Major roads, Y-coord	0.58	3.7	0.51	0.58
	M3	PM2.5 CTM, All roads (0.1km), Natural (0.8km), Residential, Major roads, Y-coord	0.40	4.4	0.37	0.28
	M4	PM2.5 SAT, PM2.5 CTM, All roads (0.7km), Residential, Major roads, Altitude, Y-coord	0.60	3.6	0.54	0.59
AIRBASE	M1	Natural (10km), Natural (0.4km), Urban green (10km), Altitude, Major roads (0.1km), Residential, Urban green (0.6km), Ind/comm(10km), Y-coord	0.36	4.2	0.27	0.39
	M2	PM2.5 SAT, Altitude, Natural (0.2km), All roads (0.1km), Residential (0.2km), Major roads, Y-coord	0.61	3.2	0.56	0.56
	M3	PM2.5 CTM, Altitude, Residential (0.2km), Major roads (0.1km), Natural (0.1km), Urban green (1.8km)	0.52	3.5	0.45	0.23
	M4	PM2.5 SAT, PM2.5 CTM, Altitude, Residential (0.2km), Major roads (0.1km), Natural (0.1km), Y-coord	0.63	3.1	0.58	0.52
NO_2						
ESCAPE	M1	All roads (5km), All roads (0.2km), Residential (1.8km), Major roads, Ind/comm(10km), Ports (0.4km), Y-coord	0.47	12.1	0.38	0.46
	M2	NO2 SAT, All roads (5km), All roads (0.2km), Urban green (1.8km), Residential (1.5km), Major roads, Ind/comm(10km), Ports (0.4km), Y-coord	0.51	11.6	0.40	0.51
	M3	NO2 CTM, Major roads, Residential (1.5km), All roads (0.2km), All roads (2km), Urban green, Y-coord	0.57	10.9	0.44	0.55
	M4	n.a.				
AIRBASE	M1	All roads (2km), Major roads (0.1km), Total build up (10km), Natural (1.5km), Residential (0.5km), Ports (0.2km), Altitude, All roads, Y-coord	0.51	10.1	0.54	0.37
	M2	NO2 SAT, Major roads (0.1km), All roads (10km), Residential (1.8km), Ports (0.2km), Residential (0.3km), All roads (10km), Y-coord	0.54	9.9	0.55	0.42
	M3	NO2 CTM, Major roads (0.1km), All roads (2km), All roads, Ports (0.2km), Residential (0.3km), Natural (0.5km)	0.58	9.4	0.60	0.50
	M4	n.a.				

Model 3 AIRBASE NO_2

Transect (red line in Inset 1) through Paris and surrounding area (0-230km) showing the contribution of each predictor variable of Model 2 (in µg/m³) and the final modelled NO_2



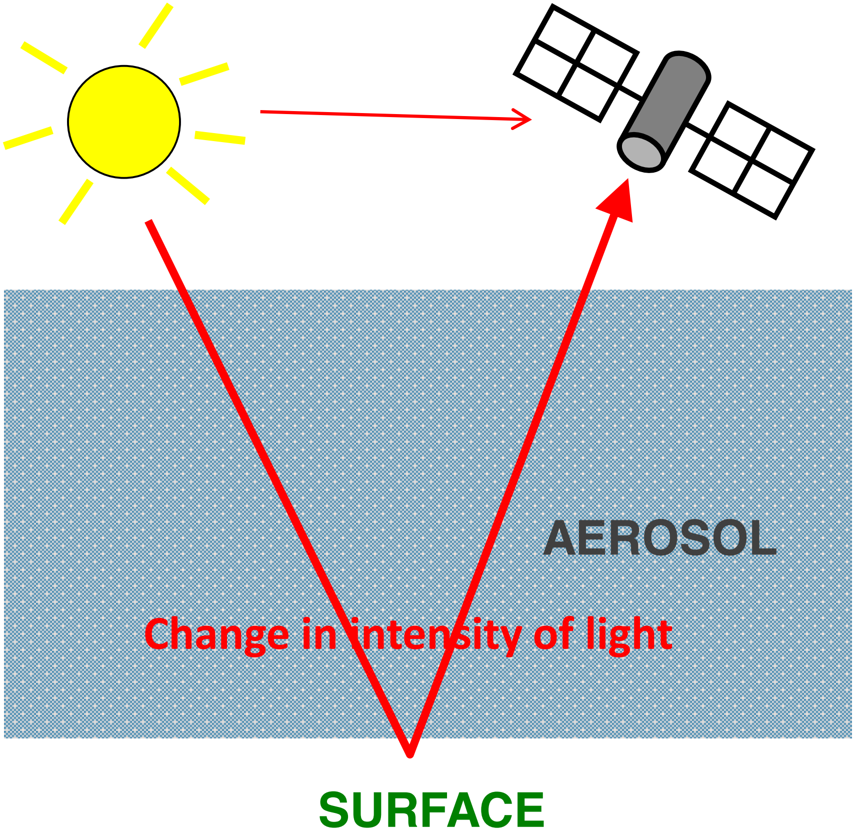
Satellite data



Aerosol Optical Depth: Definition

Swiss TPH

➢"Aerosol Optical Depth“ (AOD) or "Aerosol Optical Thickness“- measures the light extinction (reduction of light) by aerosol scattering and its absorption in the atmospheric column.



arpae emilia-romagna

Modelling of short-term air pollution

Swiss TPH

- Sophisticated spatiotemporal hybrid models (2003 – 2013) developed allowing estimation of daily exposures.
- Models are based on a method developed by Kloog et al. (2013) incorporating satellite-derived aerosol optical depth (AOD) measurements together with spatial and temporal predictors like land use, road traffic, meteorology and altitude.
- To this date, this method has been successfully applied to

Region	Out-of-sample R2	Reference
New England (U.S.),	0.81	Kloog et al., 2011
the Mid-Atlantic region (U.S.)	0.81	Kloog et al., 2012
North-eastern USA (U.S.)	0.88	Kloog et al., 2014
Mexico City (Mexico)	0.72	Just et al., 2015

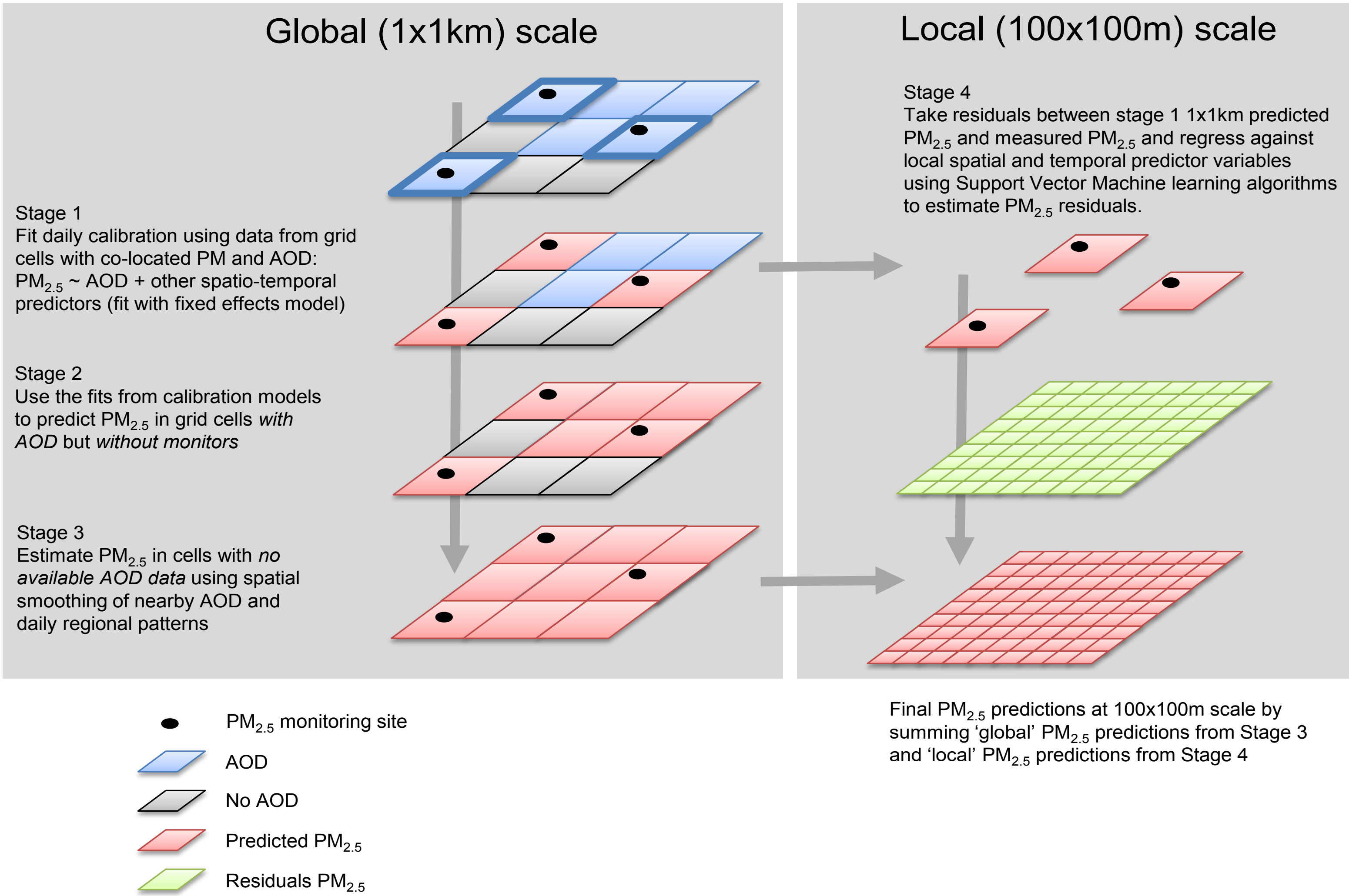
Key points

- AOD measures light scattering by a column of air up to the satellite
- We care about concentrations near the ground
- Some days more of the particles are near the ground

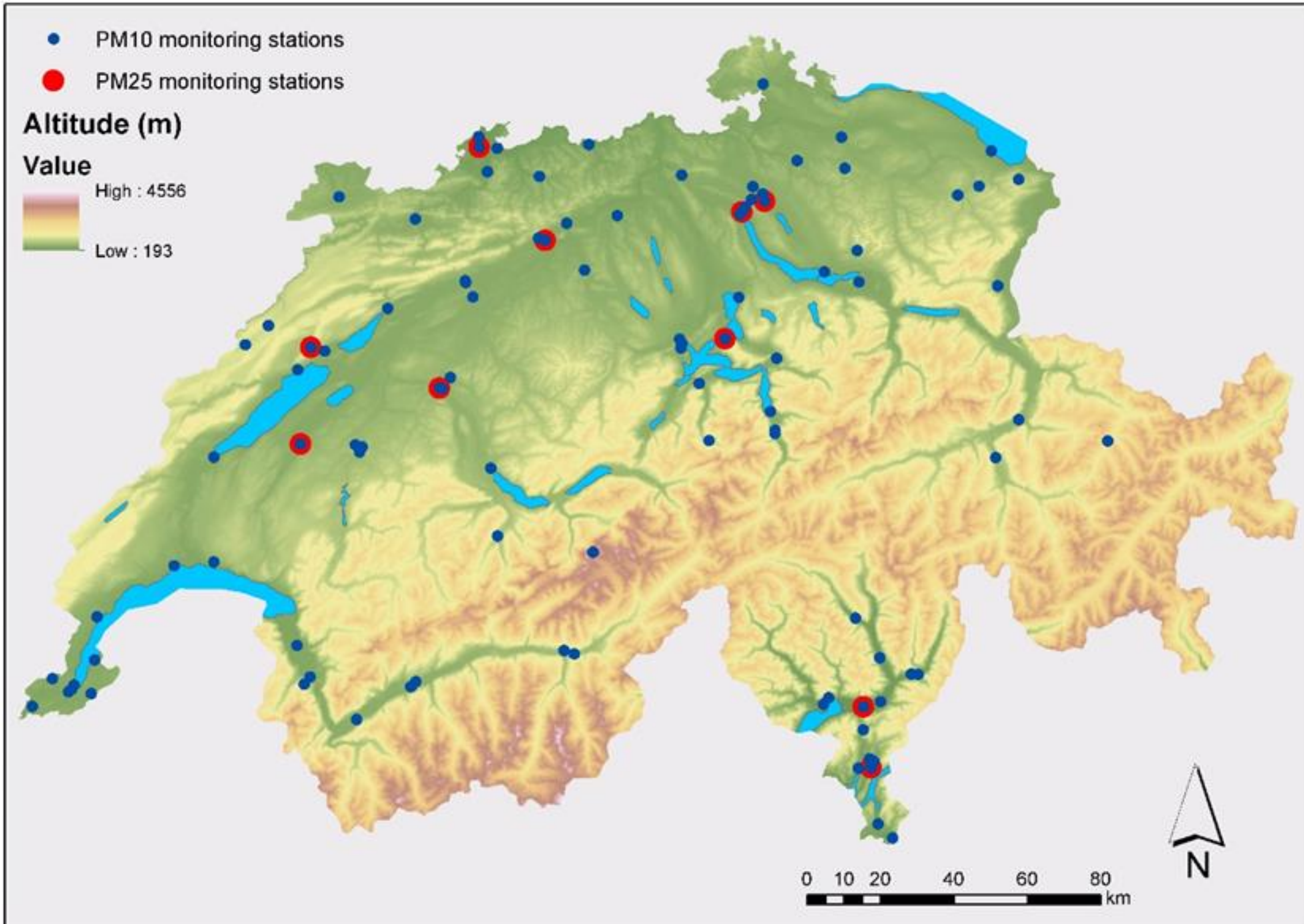
➢ The earth is characterized by a mixing height, below which particles mix vertically fairly well

- So, on days when the mixing height is low, more of the particles emitted are trapped near the earth, and $PM_{2.5}$ concentrations are higher for the same AOD
- Solution: Interaction term between AOD and mixing height
- Similarly using land use terms for each grid cell can help

Flow diagram

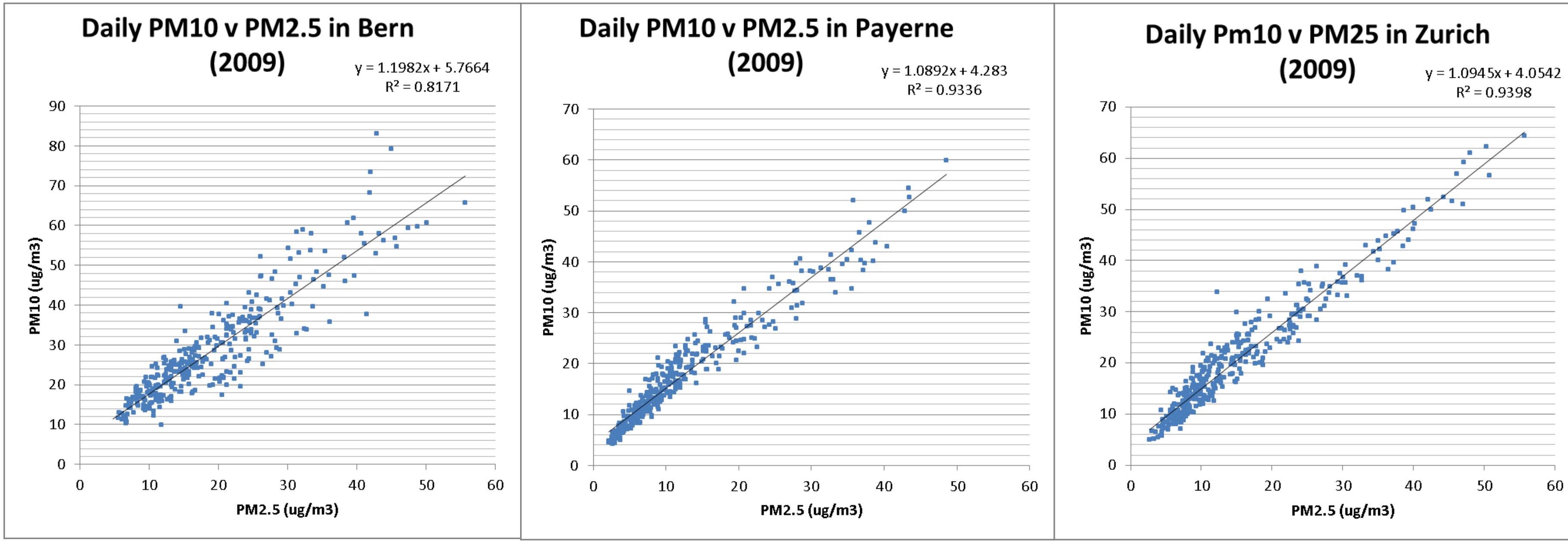


$PM_{2.5}$ and PM_{10} monitoring (2003-2013)

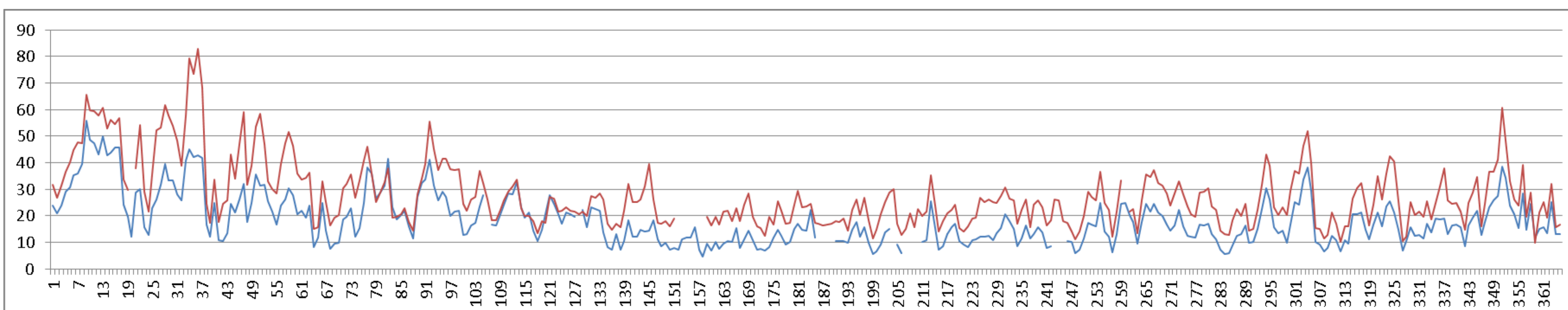


Correlation $PM_{2.5}$-PM_{10} at co-located sites

Swiss TPH



Daily PM_{10} (red) and $PM_{2.5}$ (blue) in Bern (µg/m³, 2009)



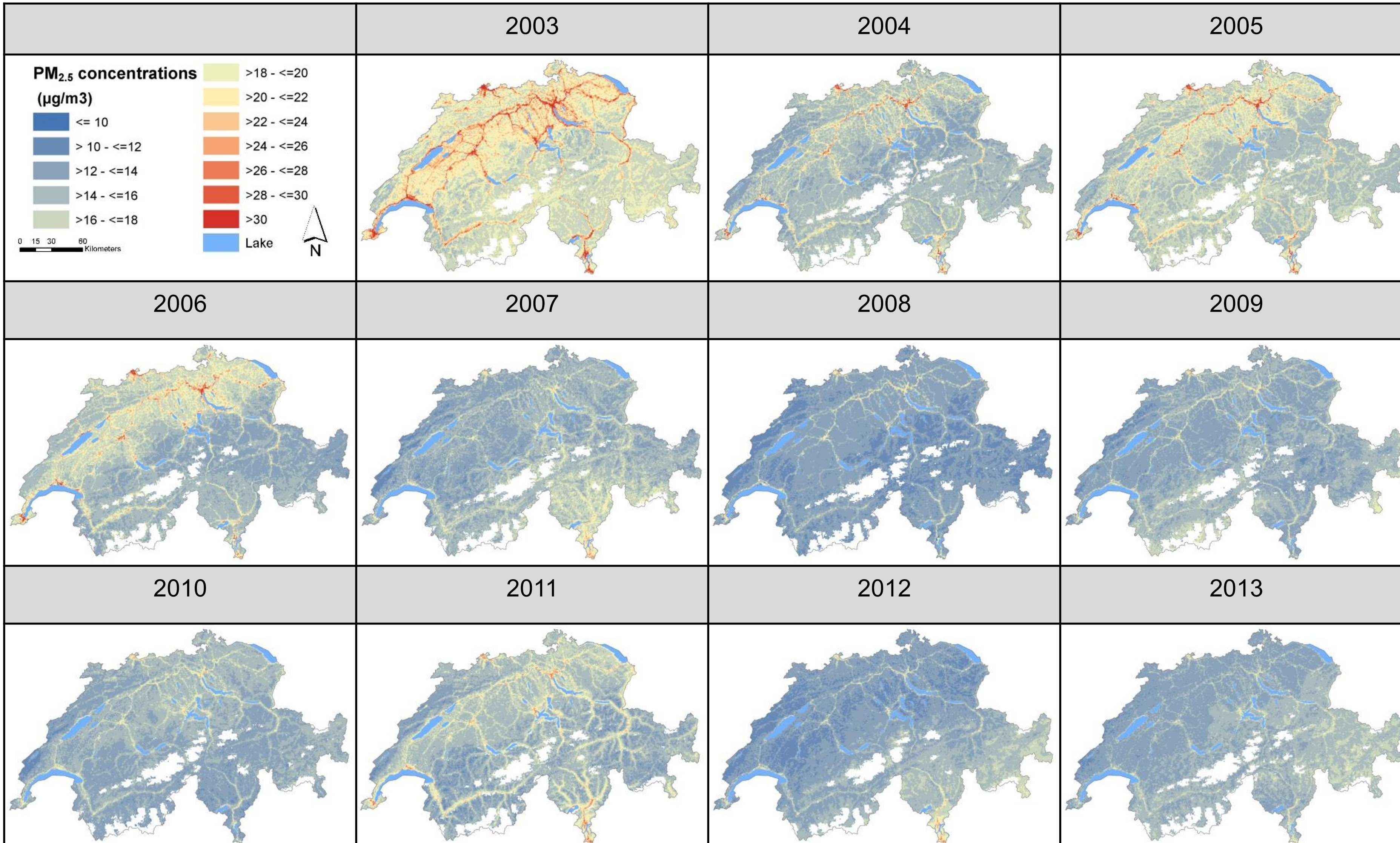
Other predictor data

Swiss TPH

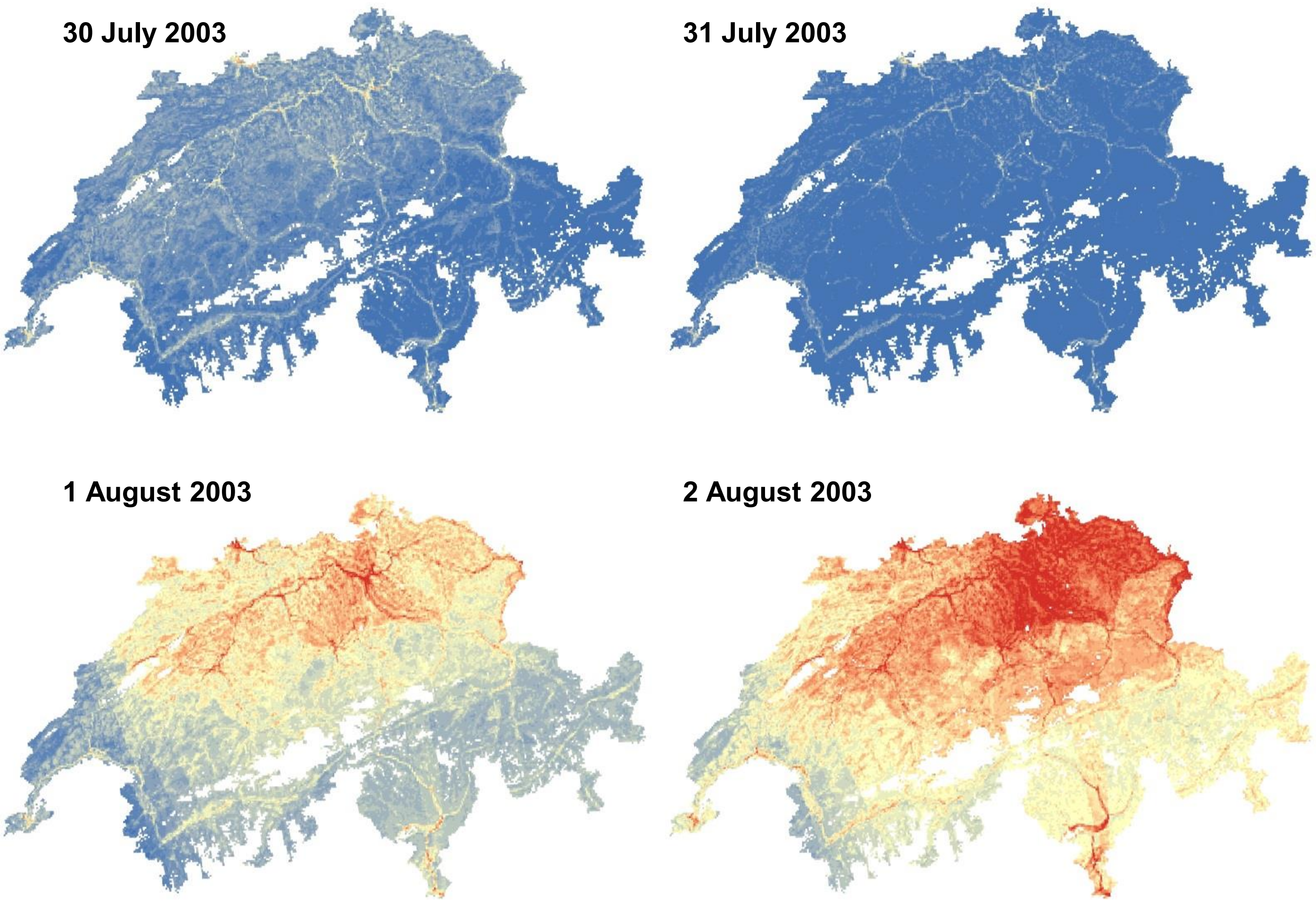
- ***Road density***; 1:25'000 VECTOR25 road data (SwissTopo).
- ***Land Use***; 100 m European Corine Land Cover (CLC2006)
- ***Traffic density***; sonBASE traffic database which is linked to the VECTOR25 road network.
- ***Emissions***; PM2.5 (2005, 2010) and NO2 (2005, 2010, 2015) emissions at a 1x1km grid, covering agriculture, household, industry, traffic and wood smoke emissions (FOEN, 2011 and FOEN, 2013) (MeteoTest).
- ***Meteorology***; daily temperature, wind speed, wind direction, humidity, cloud cover, global radiation and precipitation (MeteoSwiss)
- ***Elevation***: SRTM Digital Elevation Database version 4.1(CGIAR-CSI) with a resolution of one arc second (approximately 90 m) and a vertical error <16 m.

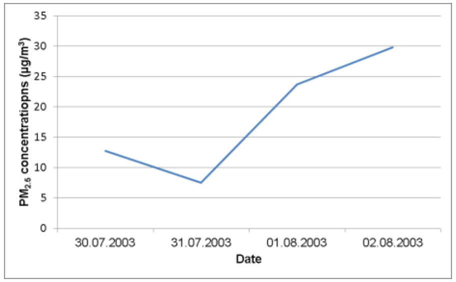
Annual modelled $PM_{2.5}$ 2003 - 2013

Swiss TPH

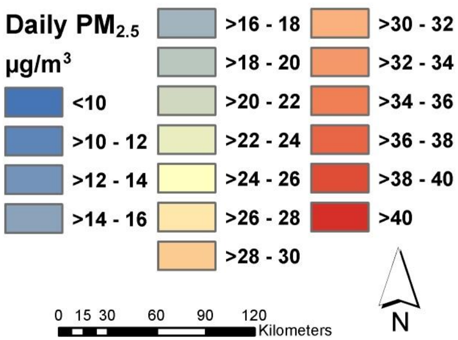


Daily PM2.5 for 4 consecutive days





Observed daily average $PM_{2.5}$ concentrations (µg/m^3) calculated as the average $PM_{2.5}$ across all 99 operating sites in Switzerland

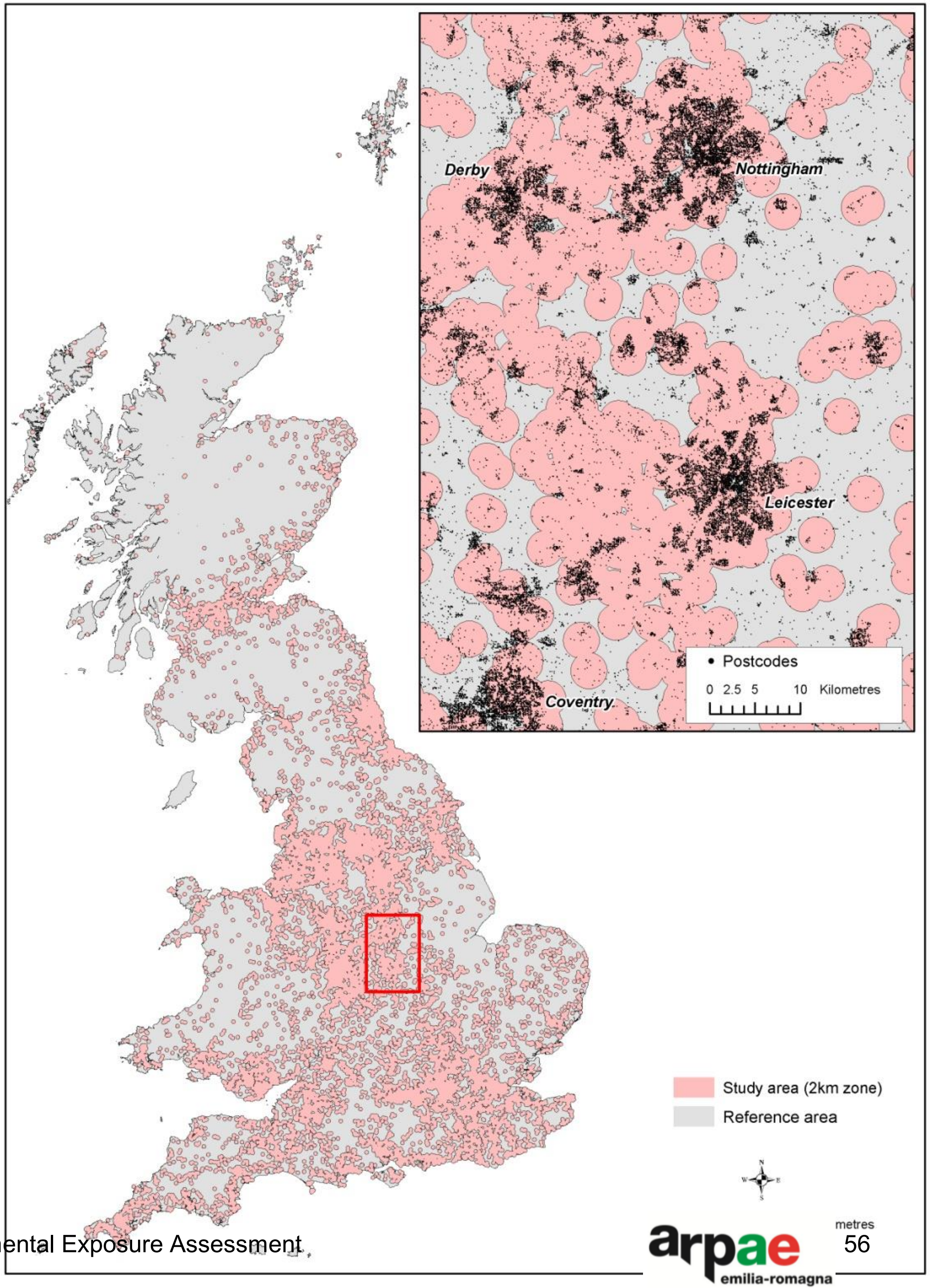


Examples

Risk of adverse birth outcomes in populations living near landfill sites

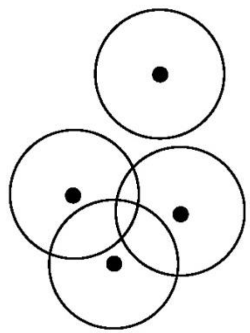
Elliott P, Briggs D, Morris S, de Hoogh C, Hurt C, Jensen T K, Maitland I, Richardson S, Wakefield J, and Jarup L. BMJ 2001;323:363-368

- Areas within 2 km of a landfill site in Great Britain

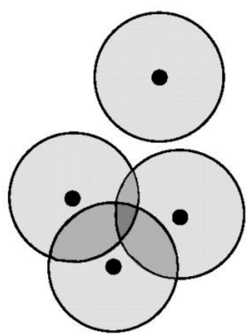


Exposure assessment

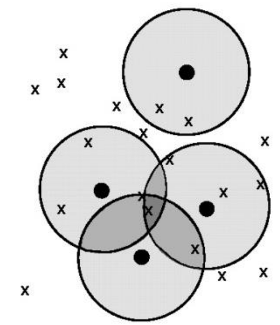
a) Construct separate 2km buffers around each landfill site



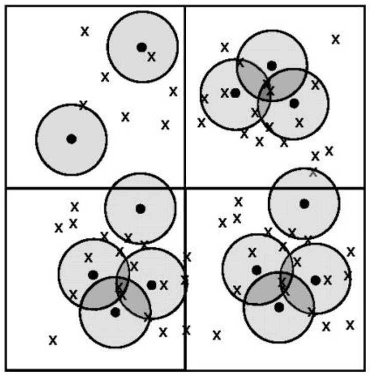
b) Intersect buffers and create density map with number of overlaps (landfill sites within 2km) attributed to each polygon



c) Intersect density map with postcodes and attribute number of landfill sites to each postcode



d) Intersect with 5km grid cells and compute birth- and time-weighted landfill index for each cell



Cancer Risk Near a Polluted River in Finland

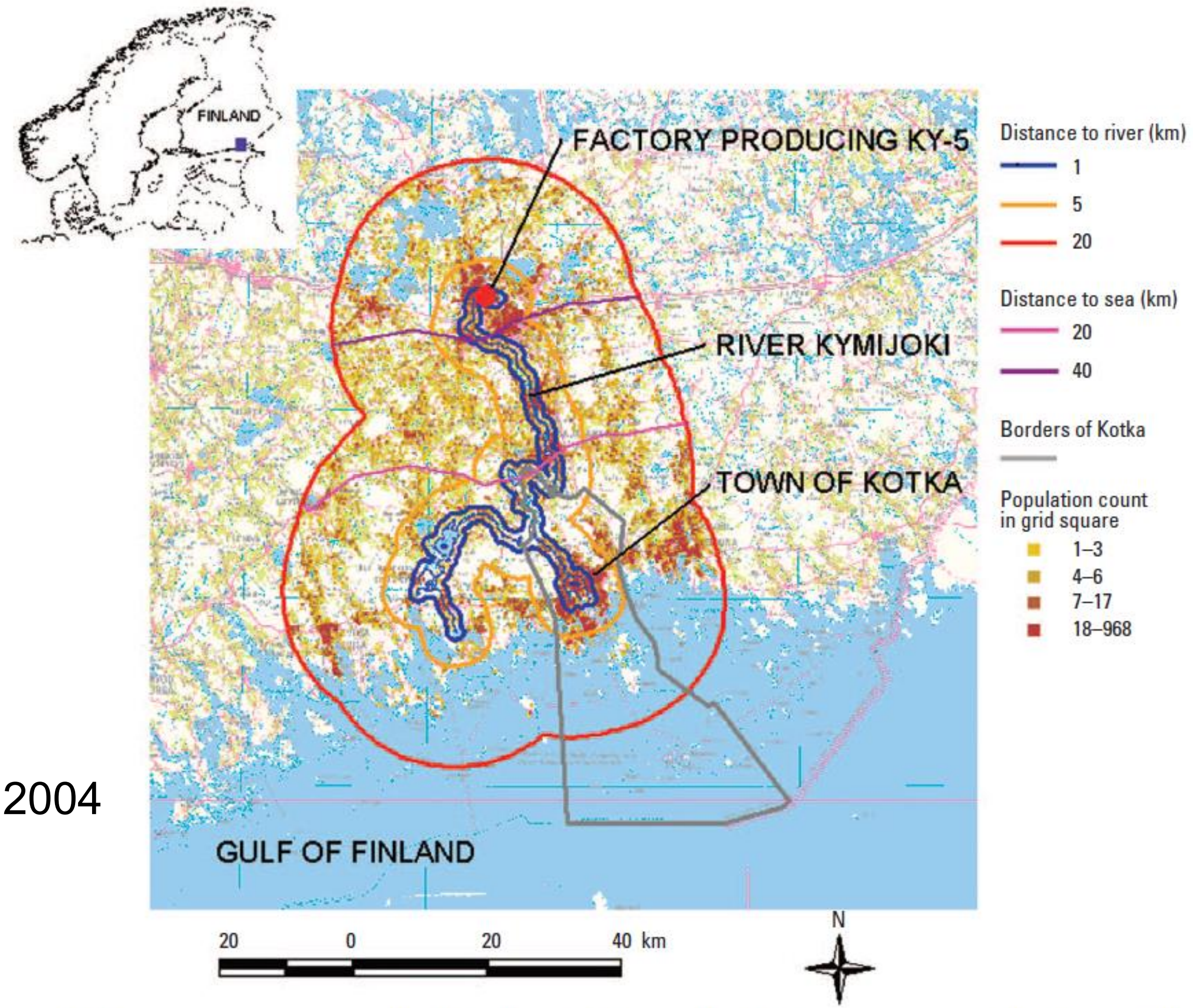
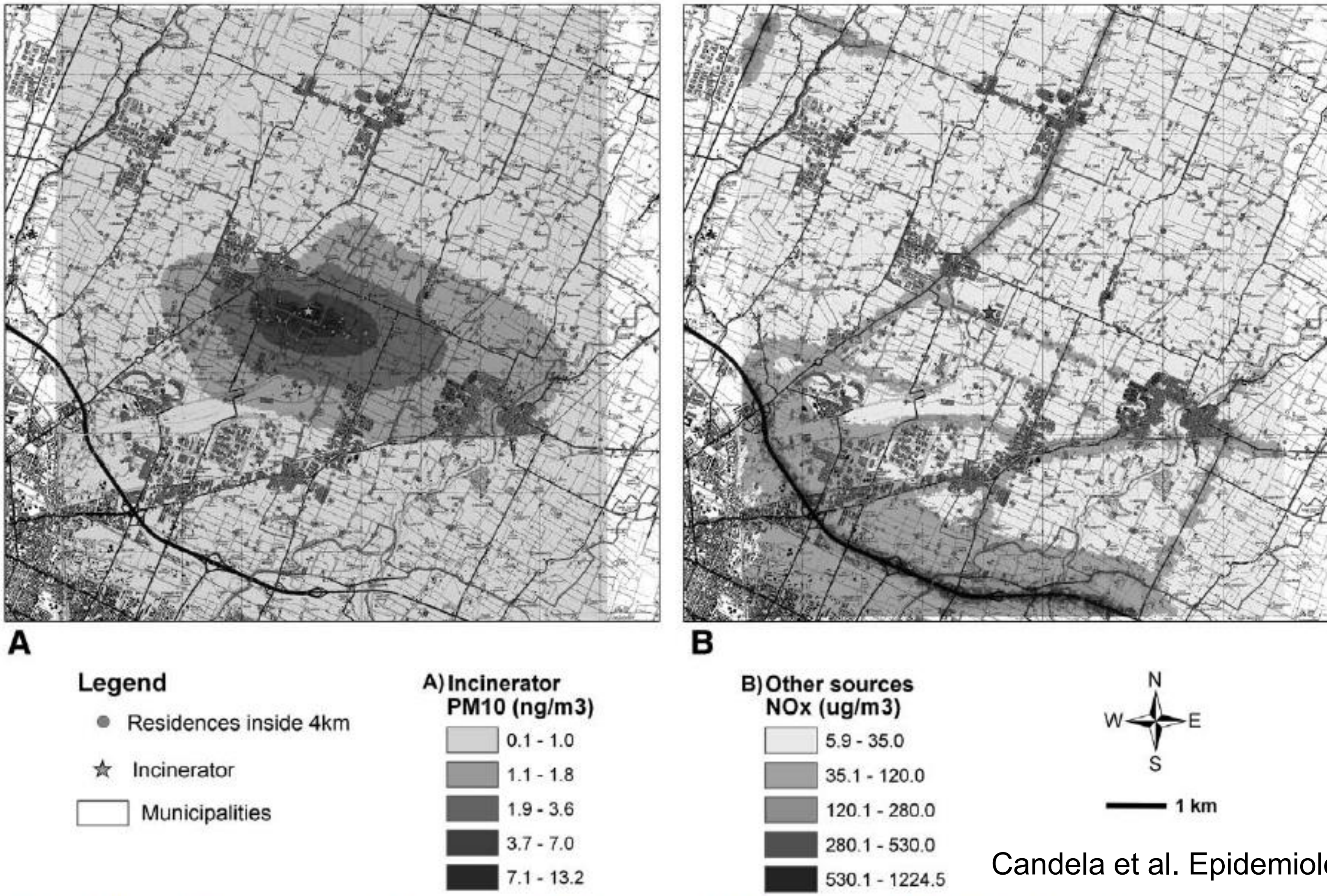


Figure 1. Exposure zones around the River Kymijoki. Reproduced with permission of the National Land Survey of Finland.

Verkasalo et al, EHP, 2004

Air Pollution from Incinerators and Reproductive Outcomes

Swiss TPH



Candela et al. Epidemiology 2013

FIGURE 1. Pollutant dispersion map of Bologna site: A, PM_{10} (year 2006) for incinerator; B, NO_X for other sources.

Characterization of soil heavy metal contamination and potential health risk in metropolitan region of northern China

Fig. 1 Map of study area and sampling sites

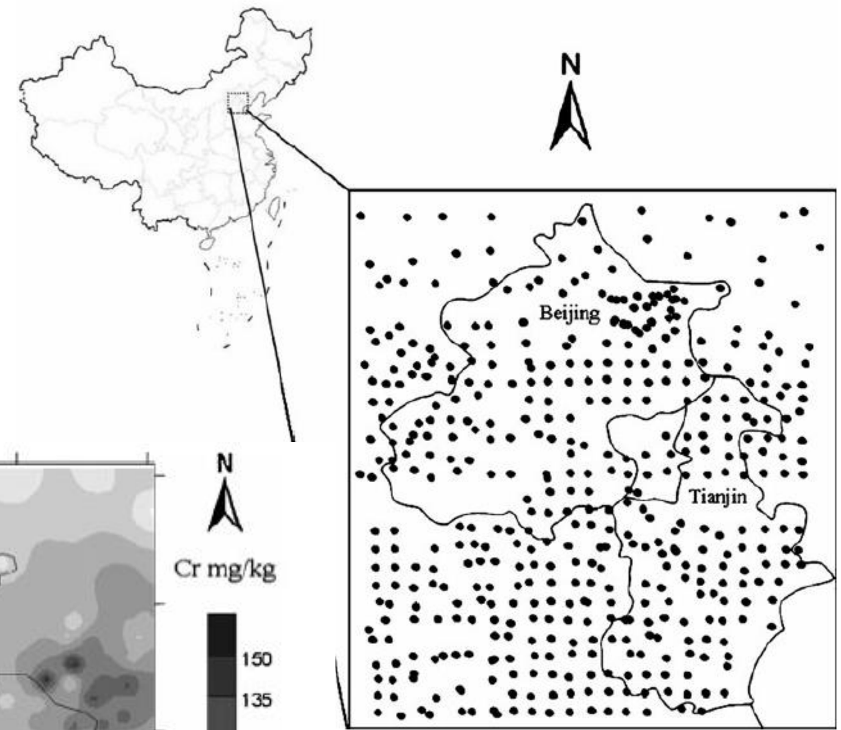
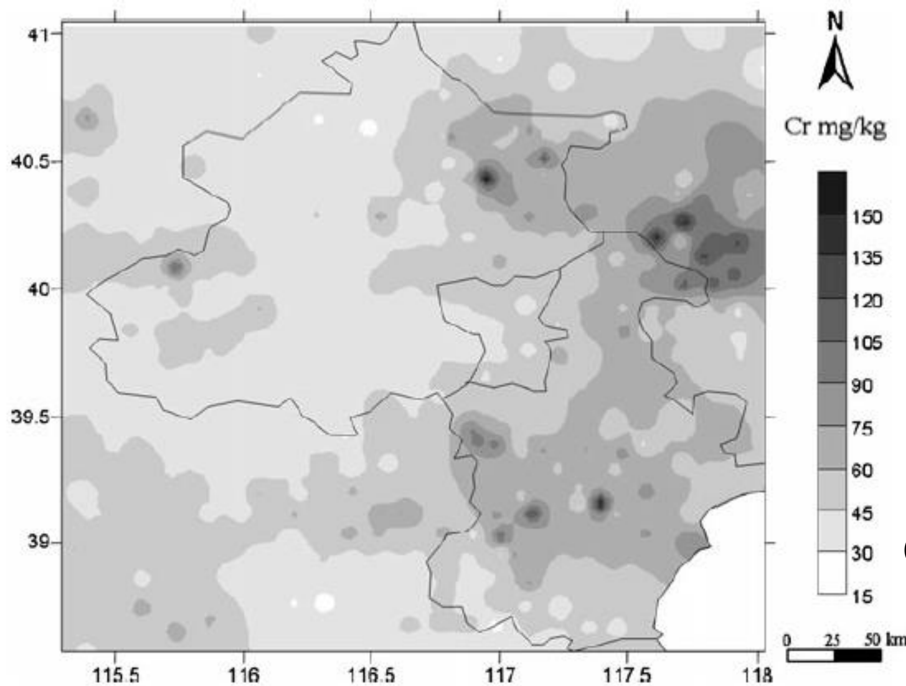


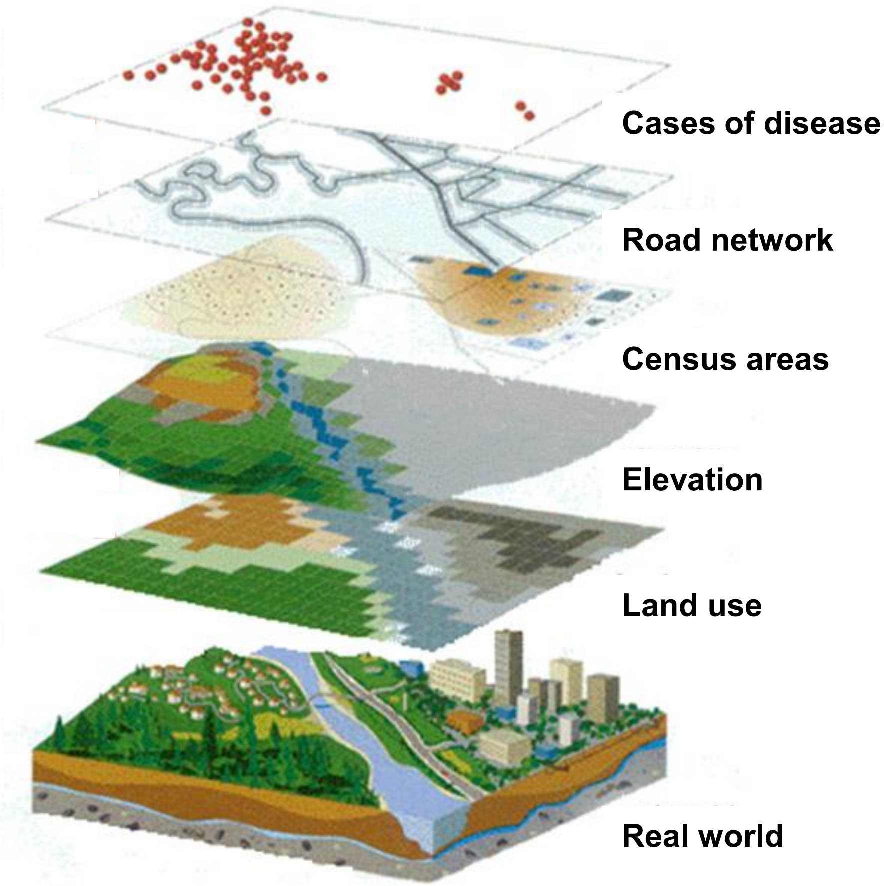
Fig. 3 Spatial distribution of Cr in topsoil from Beijing, Tianjin, and the surrounding regions



Qiao et al, 2011, Environ Monit Assess

Geographical Information Systems

- A GIS works with **layers** of spatial data



Answer questions by comparing different layers of data