INTEGRATION OF MODELLING AND PERSONAL EXPOSURE MONITORING OF AIR POLLUTION

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Workshop

Quantifying the impact of air pollution on health

Glasgow University, 12th September 2014

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Overview

- Introduction – Air pollution and human health
- Regulatory air pollution monitoring
- Personal exposure monitoring
- Atmospheric dispersion modelling: EMEP4UK
- Example: modelling personal exposure in EMEP4UK
- Conclusions, outlook and challenges

Air pollution and human health

- **WHO IARC: *Outdoor air pollution a leading environmental cause of cancer deaths*** *(17 Oct 2013)*
- **WHO:** In the year 2008, urban outdoor air pollution was responsible for 1.3 million annual deaths, representing 2.4% of the total deaths. Worldwide, urban air pollution is estimated to cause about 9% of the lung cancer deaths, 5% of cardiopulmonary deaths and about 1% of respiratory infection deaths.
- **Particulate matter** pollution is an environmental health problem that affects people worldwide, but middle-income countries disproportionately experience this burden.

Specific challenges

- air pollutant concentrations are highly variable in space and time
- people move around, spending time indoors and outdoors, different activities, varying susceptibility to pollution effects

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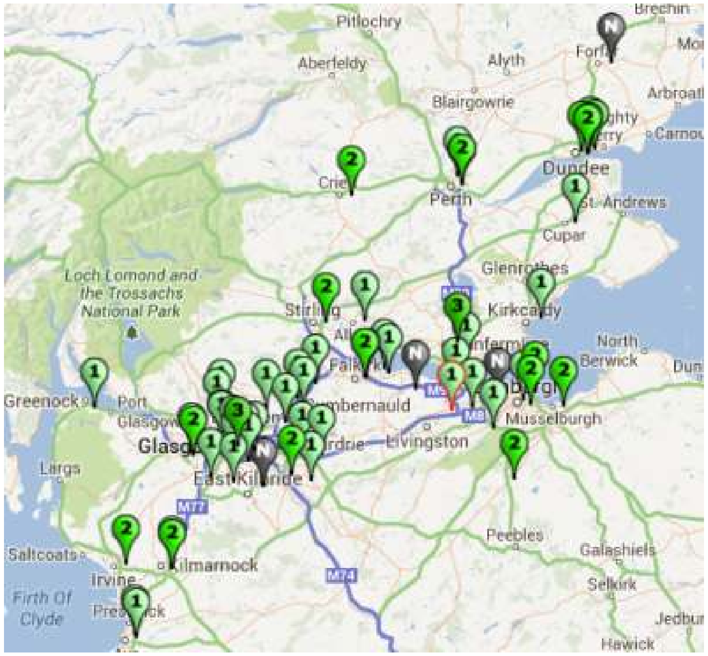
Air pollution monitoring



- ❑ Monitoring stations serve a specific (regulatory) purpose and focus on urban areas primarily *(example for Scotland's central belt):* all sites monitoring particulate matter (PM) top, sites monitoring $PM_{2.5}$ bottom

- ❑ While the urban population is traditionally most exposed, the existing monitoring sites are too sparsely distributed to provide robust and detailed information for research into air pollution effects and exposure-response relationships, or to determine association between air pollution and health effects - see e.g. Willocks *et al.* (2012).

Automatic monitoring stations in central Scotland: all PM (top) and $PM_{2.5}$ (bottom)
http://www.scottishairquality.co.uk/

Willocks LJ, Bhaskar A, Ramsay CN, Lee D, Brewster DH, Fischbacher CM, et al. Cardiovascular disease and air pollution in Scotland: no association or insufficient data and study design? BMC Public Health 2012; 12

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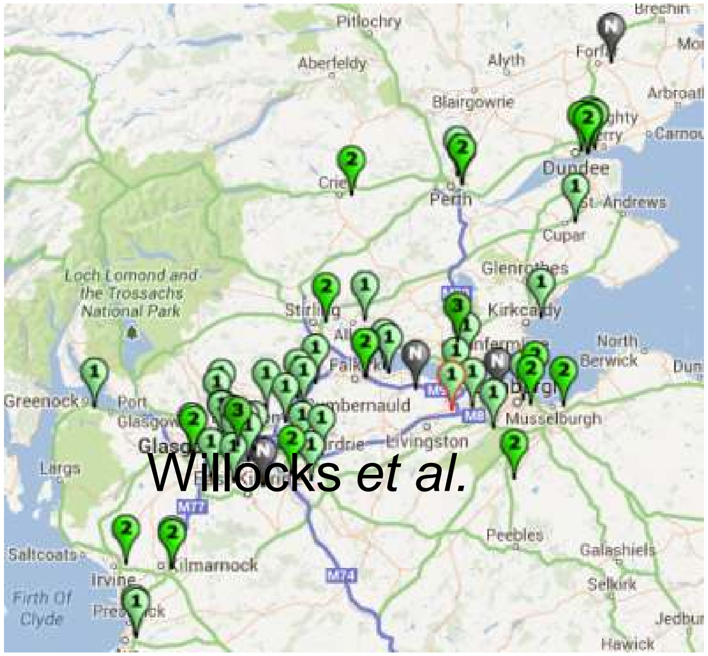
Air pollution monitoring



- Willocks *et al.*, 2012 conclude:

This study suggests that in small cities, where air quality is relatively good, then either PM_{10} concentrations have no effect on cardiovascular ill health, or that the routinely available data and the corresponding study design are not sufficient to detect an association.

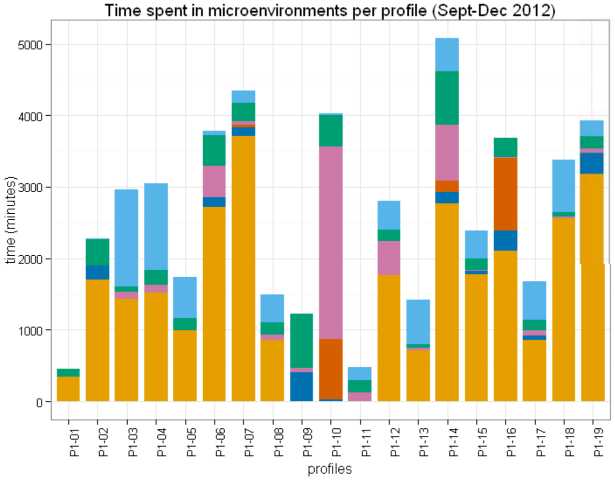
Relative risks (RR) and 95% confidence intervals (CI) for an increase of 10 micrograms per cubic metre in PM_{10} in Edinburgh and Glasgow at lags zero to five (Willocks *et al.*, 2012)

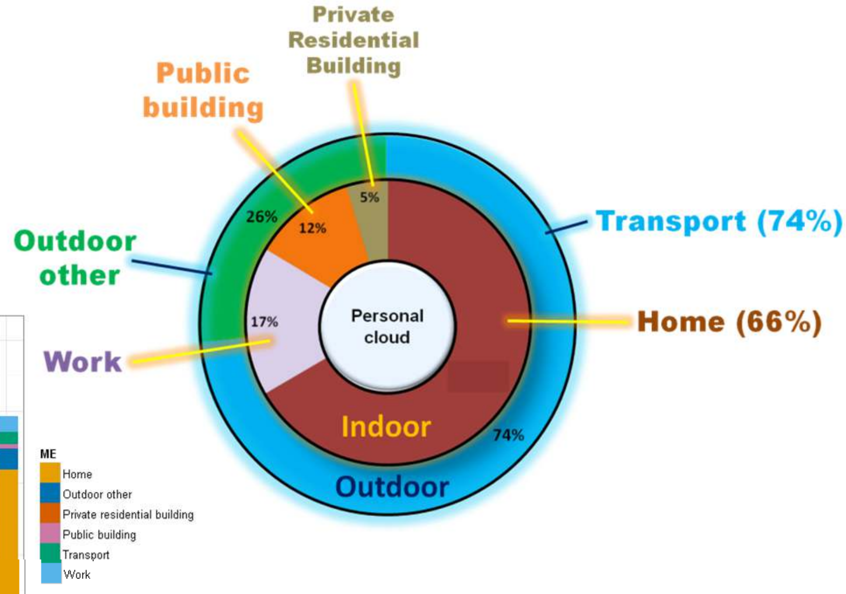
	Edinburgh		Glasgow	
Lag	**RR**	**95% CI**	**RR**	**95% CI**
0	0.9998	(0.9825, 1.0175)	1.0017	(0.9917, 1.0117)
1	1.0015	(0.9840, 1.0192)	1.0015	(0.9915, 1.0117)
2	0.9839	(0.9664, 1.0017)	1.0013	(0.9912 1.0116)
3	0.9961	(0.9786, 1.0139)	1.0023	(0.9920, 1.0126)
4	0.9950	(0.9776, 1.0128)	1.0117	(1.0016, 1.0219)
5	0.9976	(0.9801, 1.0154)	1.0073	(0.9971, 1.0175)

Willocks LJ, Bhaskar A, Ramsay CN, Lee D, Brewster DH, Fischbacher CM, et al. Cardiovascular disease and air pollution in Scotland: no association or insufficient data and study design? BMC Public Health 2012; 12

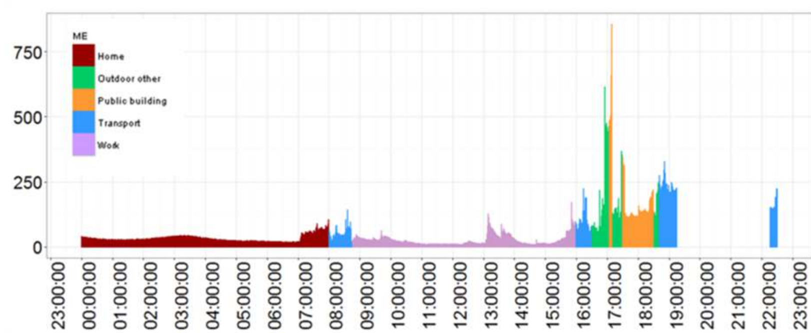
Personal exposure monitoring

Time spent in microenvironments per profile (Sept-Dec 2012)





Particle count >0.5 $\mu g/m^3$ – profile P1-17 – 20/11/2012



Steinle S, Reis S, Sabel C (2013) Quantifying human exposure to air pollution - moving from static monitoring to spatio-temporally resolved personal exposure assessment. Science of The Total Environment 443, 184–193

Steinle S, Reis S, Sabel C, Semple S, Twigg M, Braban CF, Leeson SR, Heal MR, Harrison D Lin C (2014) Application of a low-cost method to quantify human exposure to ambient particulate matter concentrations across a wide range of microenvironments. Science of the Total Environment (under revision)

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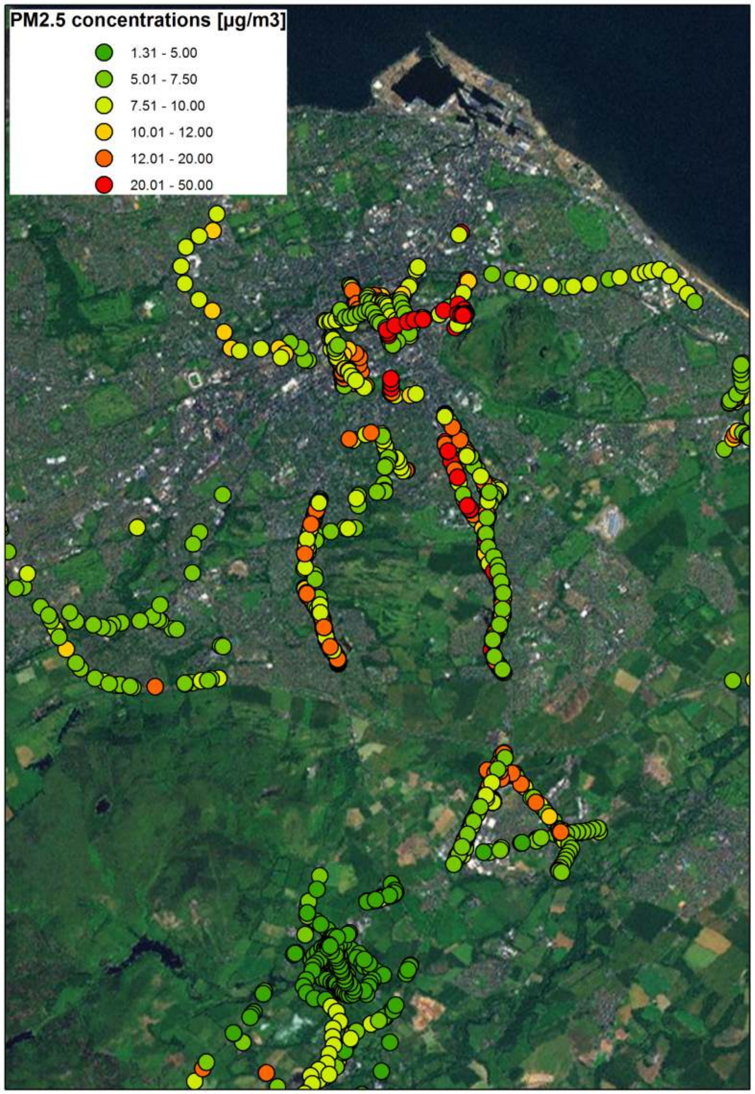
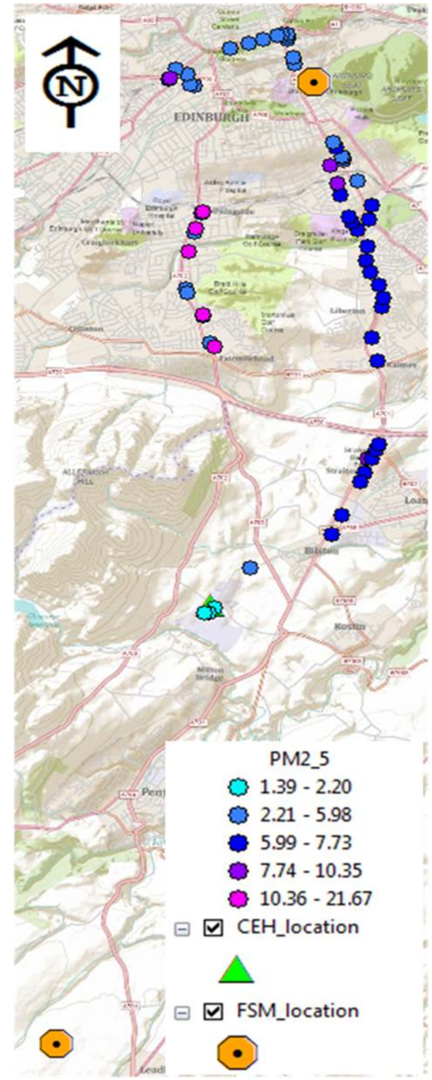
Personal exposure monitoring



- Personal monitoring allows for the detailed assessment of what pollution levels individuals are exposed to in space and time
- Compared to fixed site monitoring, the spatio-temporal variability of ambient concentrations is accounted for, as well as personal time-activity patterns.



BBC Scotland "Backpacks monitor personal air pollution" by David Miller, http://www.bbc.co.uk/news/uk-scotland-26592819

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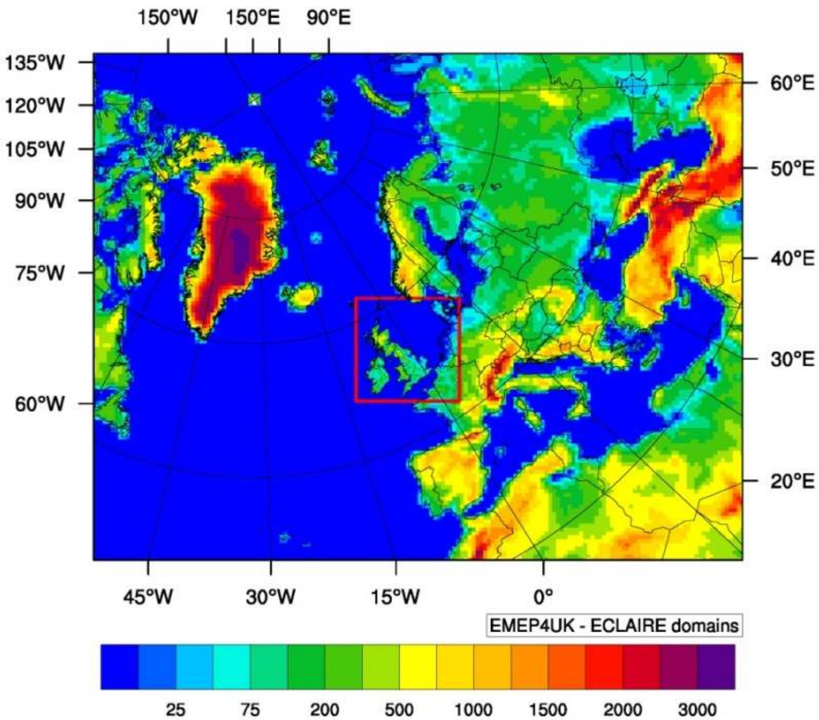
EMEP4UK- key model components



- 3D + time model in Eulerian framework
- EMEP4UK (Vieno *et. al*, 2010, 2014) - Core model derived from EMEP MSC-W model (Simpson *et al.*, 2012)
- CRIv2 R5 chemical solver (195 species, 569 reactions) Watson *et al.* (2008)
- Dry and wet deposition removal processes
- Meteorology driver is the Weather Research Forecast model (WRF 3.5 www.wrf-model.org)
- Nesting approach – Europe at 50×50 km^2, UK at 5×5 km^2 and Scotland at 1×1 km^2
- Vertical domain from surface up to 100hPa (~16 km) in terrain following coordinates
- Hourly, daily, monthly, and annual output of more than 150 species (O_3, NO_x, ..) – 2001:2012, and met variables

Simpson, D., Benedictow, A., Berge, H., Bergström, R., Emberson, L. D., Fagerli, H., Flechard, C. R., Hayman, G. D., Gauss, M., Jonson, J. E., Jenkin, M. E., Nyíri, A., Richter, C., Semeena, V. S., Tsyro, S., Tuovinen, J.-P., Valdebenito, Á., and Wind, P.: The EMEP MSC-W chemical transport model – technical description, Atmos. Chem. Phys., 12, 7825-7865, doi:10.5194/acp-12-7825-2012, 2012

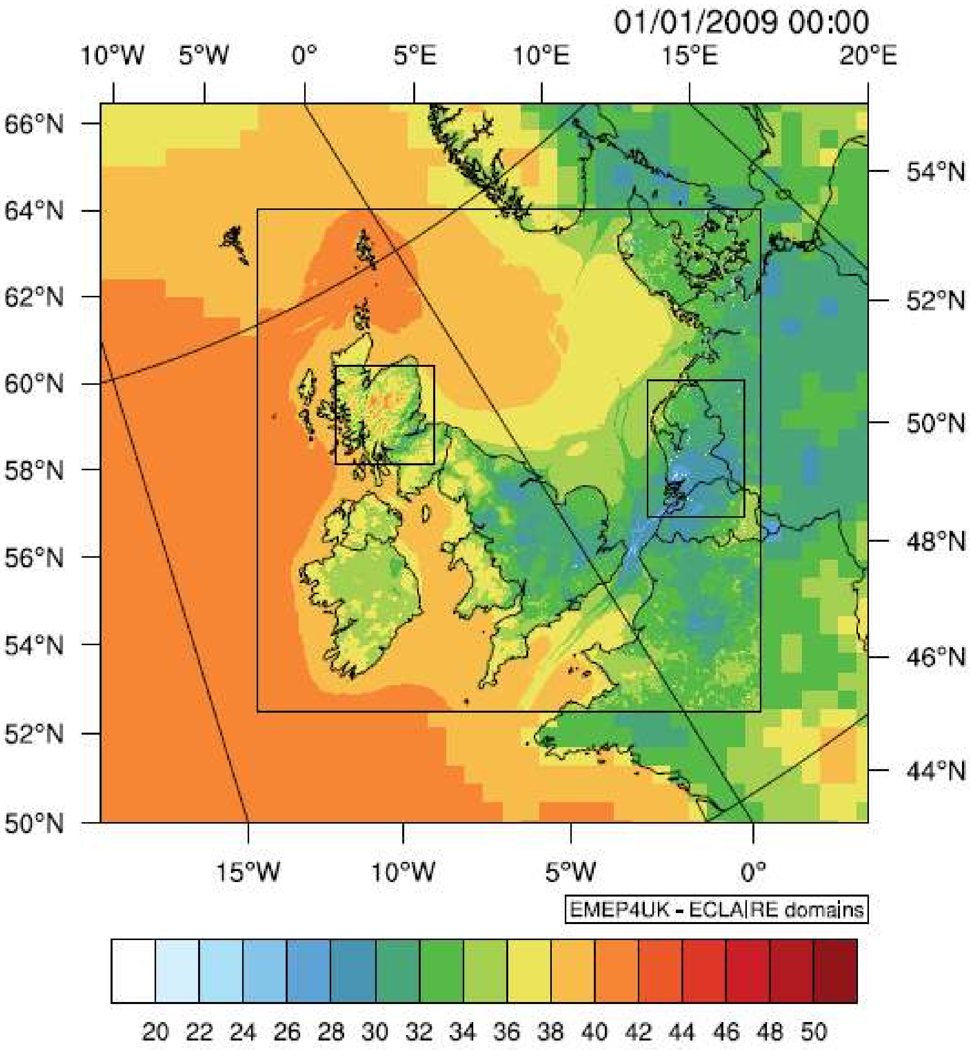
Vieno, M., Dore, A. J., Stevenson, D. S., Doherty, R., Heal, M. R., Reis, S., Hallsworth, S., Tarrason, L.,Wind, P., Fowler, D., Simpson, D., and Sutton, M. A.: Modelling surface ozone during the 2003 heat-wave in the UK, Atmos. Chem. Phys., 10, 7963–7978, doi:10.5194/acp-10-7963-2010, 2010

Vieno M, Heal MR, Hallsworth S, Famulari D, Doherty RM, Dore AJ, Tang YS, Braban CF, Leaver D, Sutton MA, Reis S (2014) The role of long-range transport and domestic emissions in determining atmospheric secondary inorganic particle concentrations across the UK. Atmospheric Chemistry & Physics (in press)

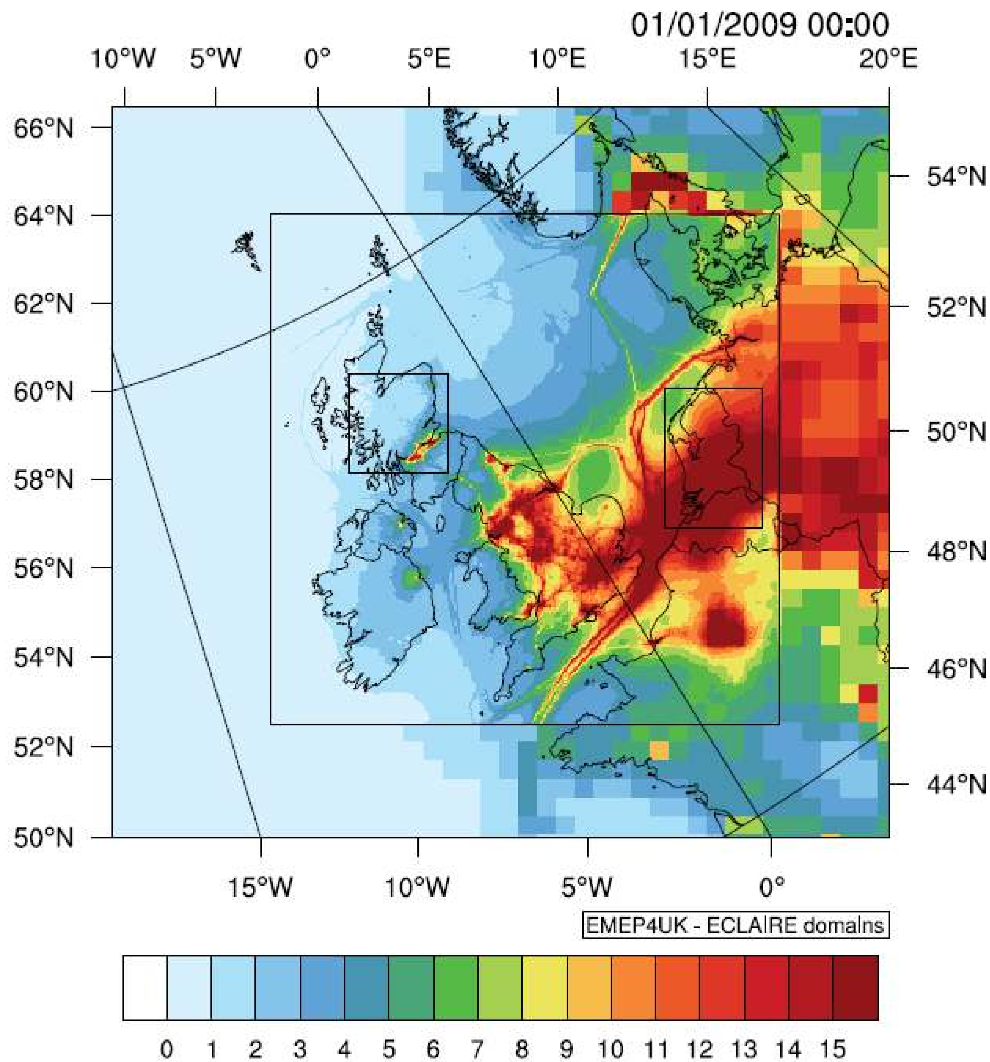
Watson, L. A., Shallcross, D. E., Utembe, S. R., and Jenkin, M. E.: A Common Representative Intermediates (CRI) mechanism for VOC degradation. Part 2: Gas phase mechanism reduction, Atmos. Environ., 42, 7196–7204, doi:10.1016/j.atmosenv.2008.07.034, 2008.

2008 EMEP4UK annual average results

O_3 concentration (ppb)



NO_2 concentration (µg m^{-3})



Results for domains 50, 5 and 1km^2

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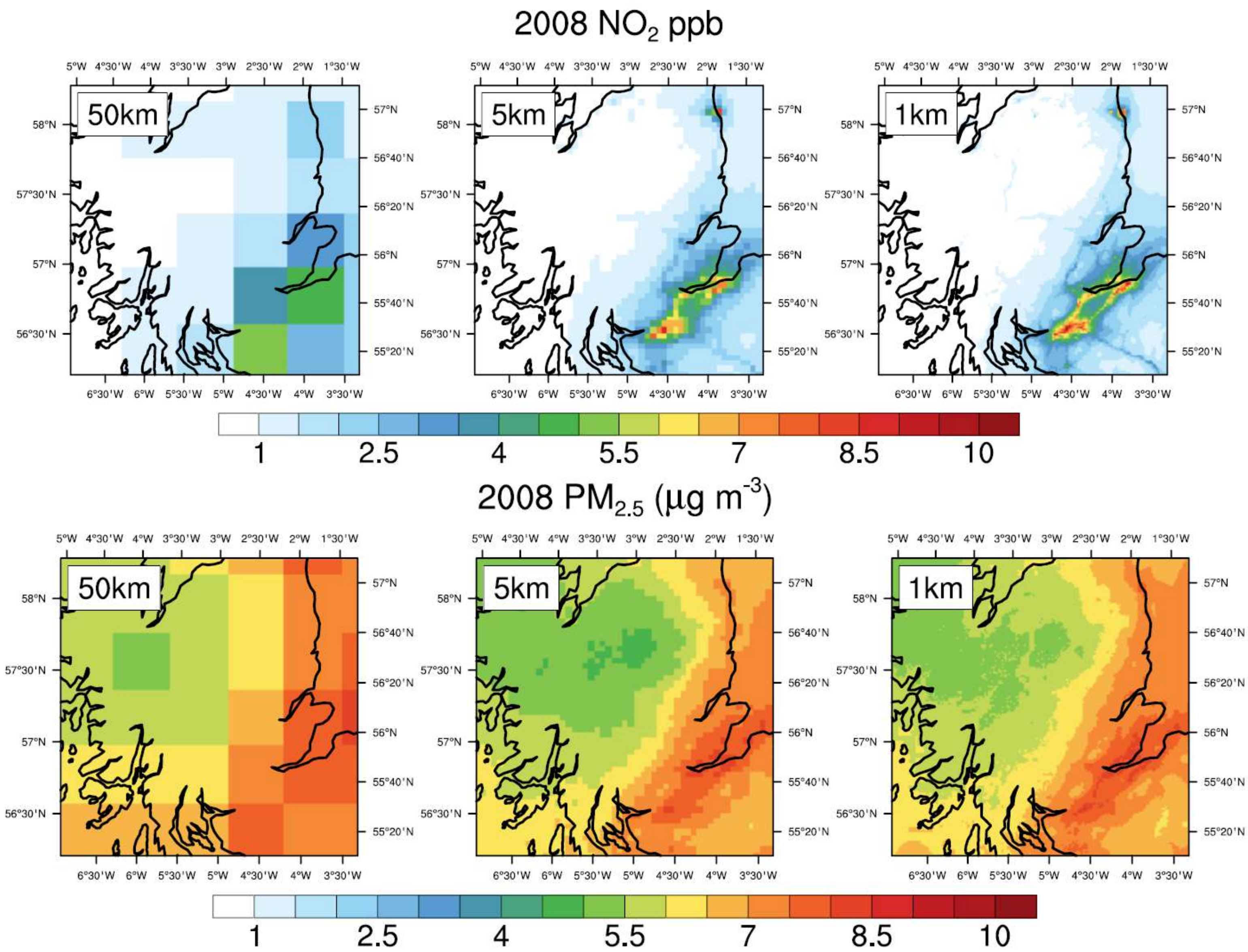
Chemistry and model resolution

Effect of resolution on ozone 1 km^2 results for the Scottish domain:



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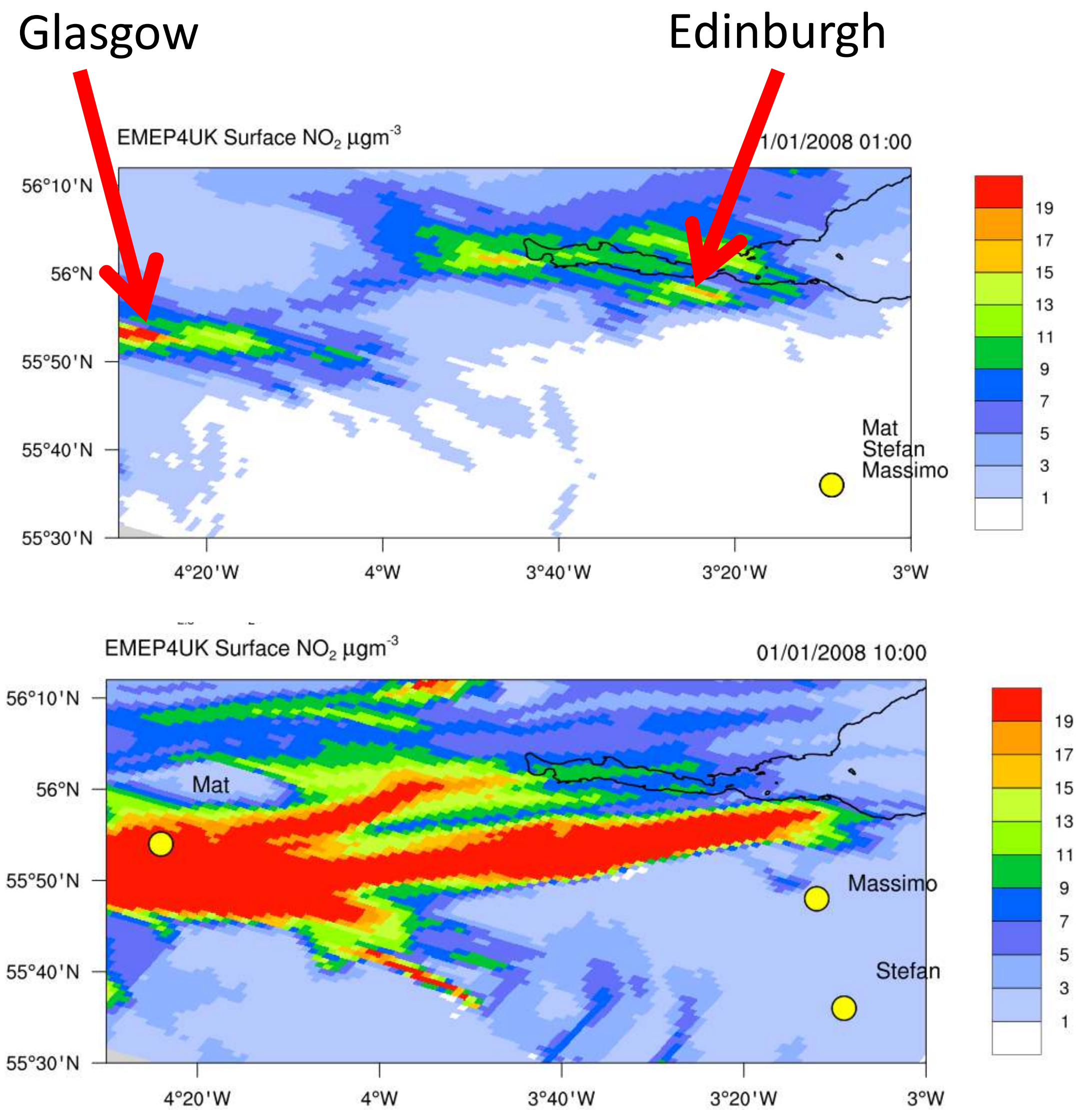
Example: modelled personal exposure



Simple case study

- Three people live in the same village near Edinburgh (UK)
- All three subject have the same working pattern 08:00 – 18:00 5 days a week, one hour commute.
  - *Massimo works in Edinburgh*
  - *Stefan works from home*
  - *Mat works in Glasgow*
- The EMEP4UK model calculates hourly surface concentrations of various pollutants (>100 species), including NO_2 and $PM_{2.5}$ which are investigated here.
- The concentration of NO_2 and $PM_{2.5}$ the three individuals are exposed to is accumulated over the appropriate time for their current location.

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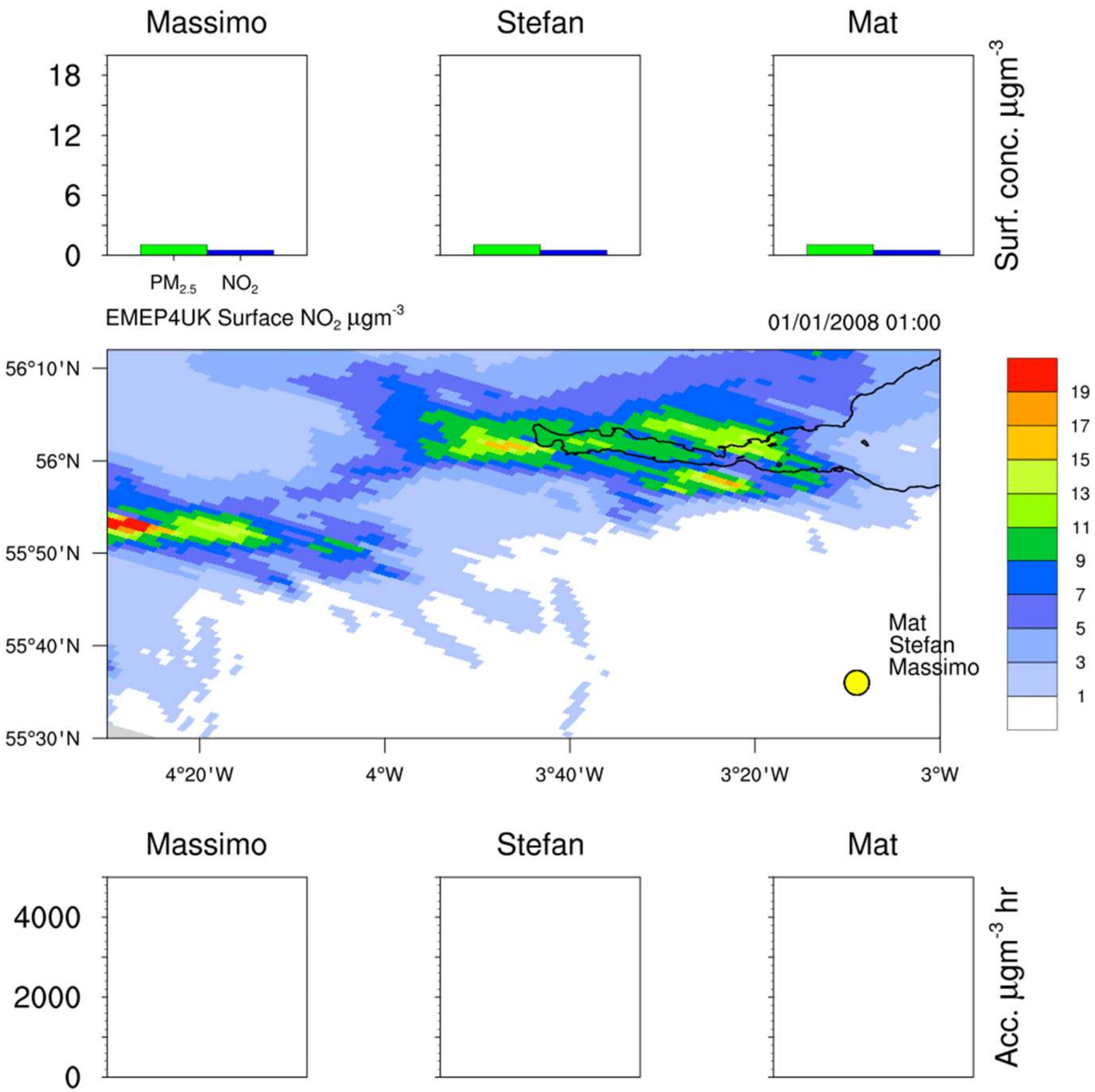
Example: modelled personal exposure



Simple case study

- For $PM_{2.5}$, the spatial variability appears to be less prominent than for NO_2
- This is caused by the better mixed occurrence of $PM_{2.5}$ (with a substantial contribution from long-range transport of secondary aerosols)
- NO_2 concentrations are subject to high spatial and temporal variability due to the contribution from road traffic and high concentrations near busy roads.

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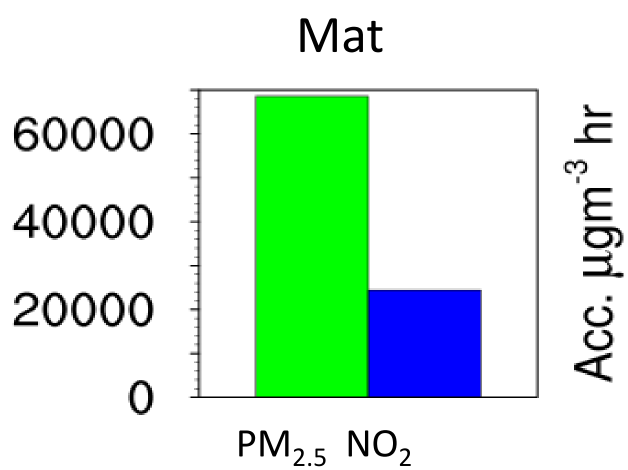
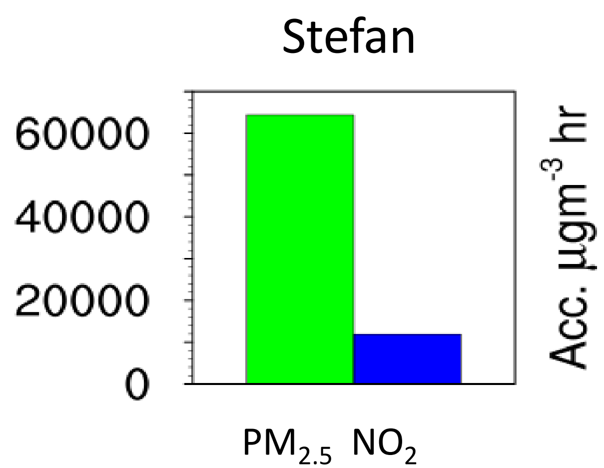
Example: modelled personal exposure

For the full year of 2008





Simple case study

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- NO_2 concentrations are subject to high spatial and temporal variability due to the contribution from road traffic and high concentrations near busy roads.
- Difference in modelled accumulated exposure between individuals is driven by their daily activity patterns, location of residence, workplace, transport mode, …
- Modelled exposure can account for a wide range of substances and mixtures, next steps will include exposures to ozone, CO, SO_2, …

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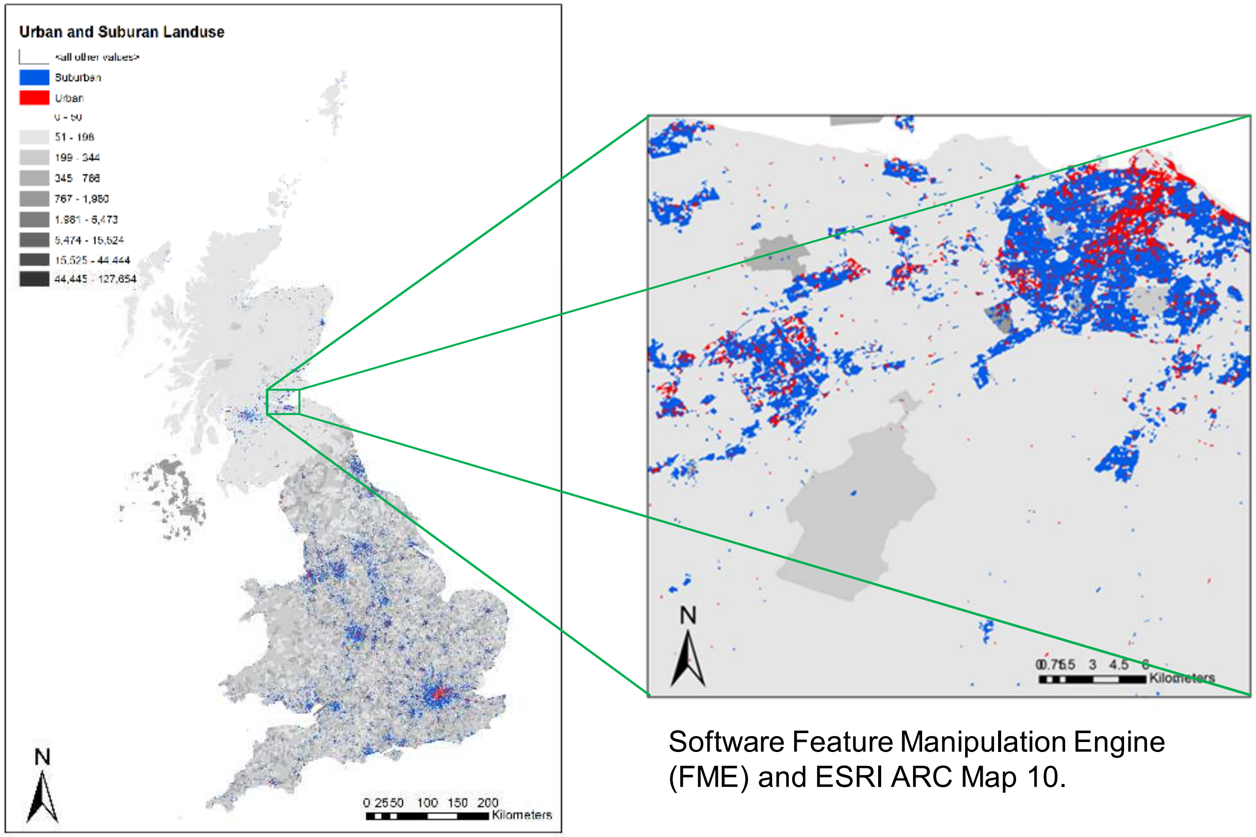
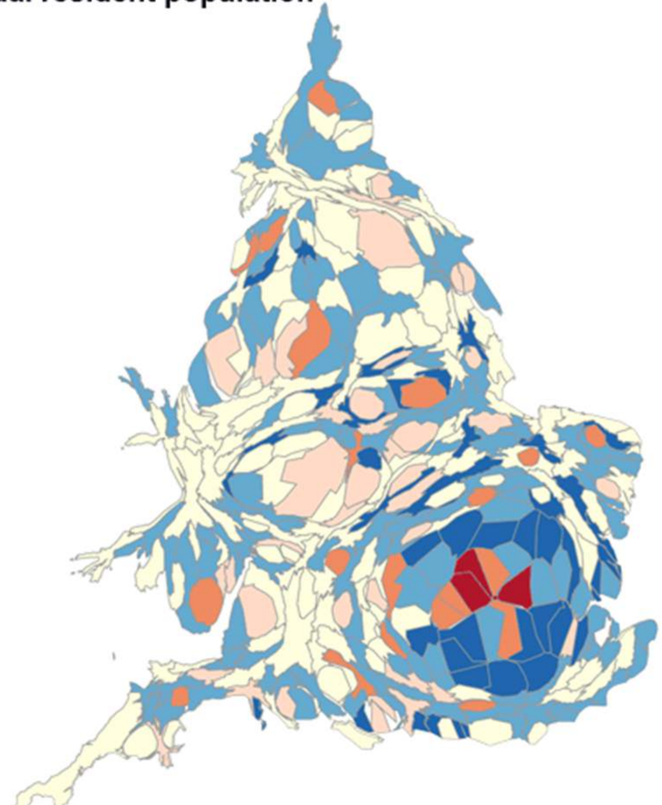
Improving exposure modelling



Software Feature Manipulation Engine (FME) and ESRI ARC Map 10.

Combination of Census 2011 population data on Output Areas (Source: Office of National Statistics, UK, 2014) and Landcover Map (LCM) 2007 (Source: Centre for Ecology & Hydrology, 2011) subclasses 'Urban' and 'Suburban' land-use for the whole of the UK (left) and the greater Edinburgh area (right).

Usual resident population



The population of the City of London increases by over 56 times during a typical work day, according to new data from the 2011 Census released by the Office for National Statistics (ONS)

Reis S, Vieno M, Steinle S, Carnell E, Beck R, Heal M, Wu H, Doherty R, Carruthers D (2014) Integrating concepts of population exposure into atmospheric dispersion models at different spatial scales, taking into account individual mobility. International Environmental Modelling and Software Society (iEMSs). 7th Intl. Congress on Env. Modelling and Software, San Diego, CA, USA, Daniel P. Ames, Nigel W.T. Quinn and Andrea E. Rizzoli (Eds.) http://www.iemss.org/society/index.php/iemss-2014-proceedings

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Conclusions

- **Static approaches** using postcode of residence and annual average concentrations will miss peak/episodic exposures and cannot account for variability due to personal activity patterns.
- **Modelled exposure** can quantify exposures to a wide **range of substances and mixtures**, but needs to utilise detailed and realistic personal activity patterns, including indoor/outdoor, transport mode, …

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Conclusions

- ***Next steps:*** **integrate intermediate data** on population mobility (e.g. UK Census 2011 workday populations) to quantify the effect of expanding modelled exposure with more spatio-temporal detail, and compare modelled personal exposure monitoring results with modelled exposure.
- **Personal activity and exposure monitoring** can provide vital data for models to account for these details, while high resolution atmospheric dispersion models can account for personal activity spaces with sufficiently high spatio-temporal resolution.

Challenges & next steps

- **Spatio-temporal resolution mismatch** between models, sensor networks and epidemiological data need to be accounted for.
- **Quality Assurance/Control** and managing uncertainties across integrated model-sensor frameworks, including improving the data quality of low-cost sensors is vital.
- Integrating **data from personal exposure monitoring activities** with **atmospheric dispersion models** to compare concentrations and exposures, learning from differences and similarities.

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Acknowledgements

The development and application of EMEP4UK is jointly funded by the UK Department for Environment, Food & Rural Affairs (AQ0727), the NERC Centre for Ecology & Hydrology, NERC and the European Commission.

Thank you for your attention!

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