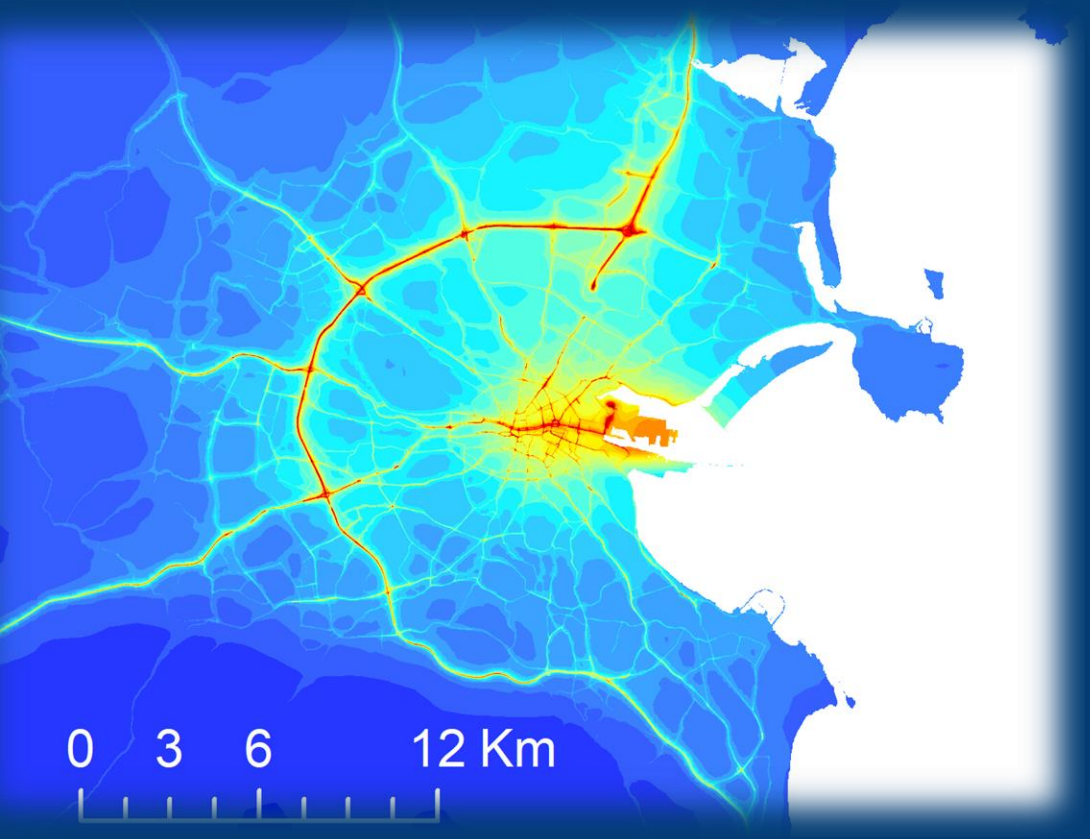
The Multi-model Air Quality System (MAQS): *description & applications*



Jenny Stocker

Clean Air Programme Conference

2nd & 3rd October 2024

Birmingham

CERC

Cambridge Environmental Research Consultants

Environmental Software and Services

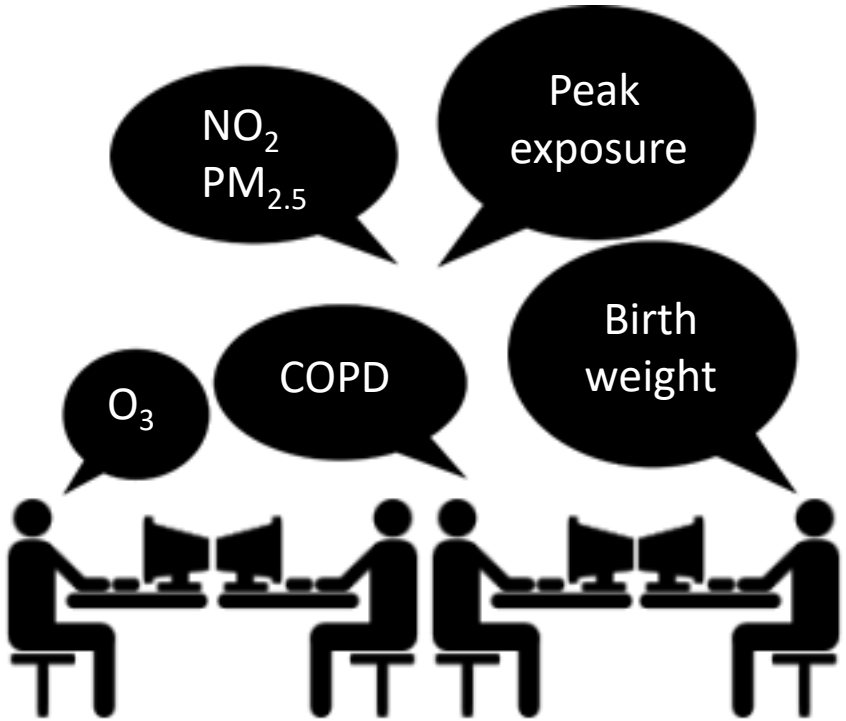
Outline

- System description
- System applications

Acknowledgments
System funders, project partners & data providers

A modelling system that enables health research

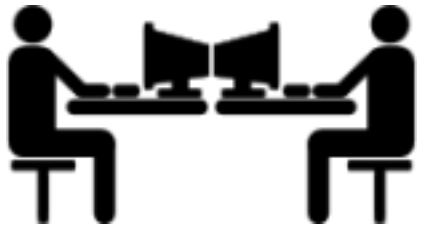
Wider community: e.g. health researchers & policy makers



Air pollutant concentration dataset requirements

Air quality modellers

High Performance Computers



Data

Regional models

Multi-model Air Quality System (MAQS)

Air pollutant concentration datasets and metrics

CERC

Pixabay.com images

MAQS-Health project requirement (2020-2022)

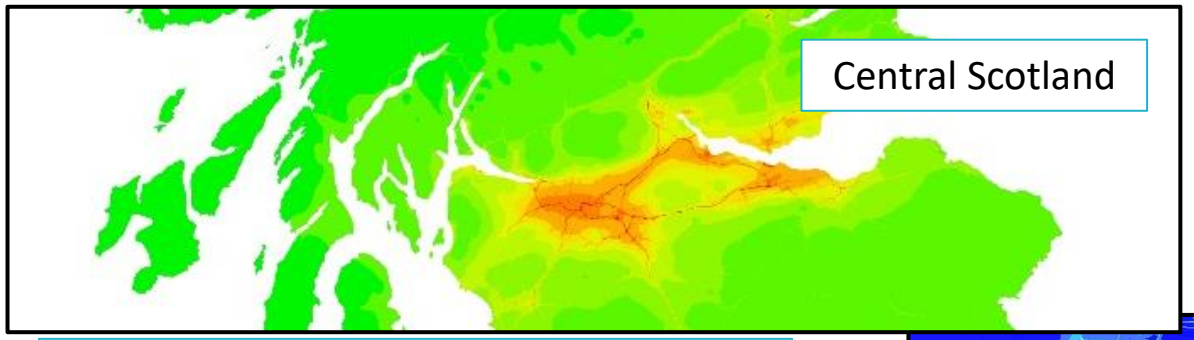
Clean Air Programme

Requirement

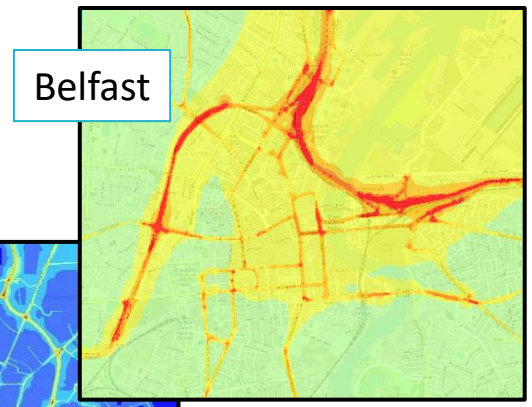
- "High resolution prediction capability to support personal exposure for health impacts, through national and local model developments" (objective of Work Package 2B within the SPF Clean Air Programme)

- ✓ MAQS-Health calculates high ***temporal and spatial*** resolution pollutant concentration fields
- ✓ A wide range of pollutant metrics can be derived from MAQS-Health datasets, useful for exposure studies
- ✓ Accuracy of modelled pollutant concentrations are easily assessed using the MAQS-Health Verification System

Smooth transition from regional to local scale

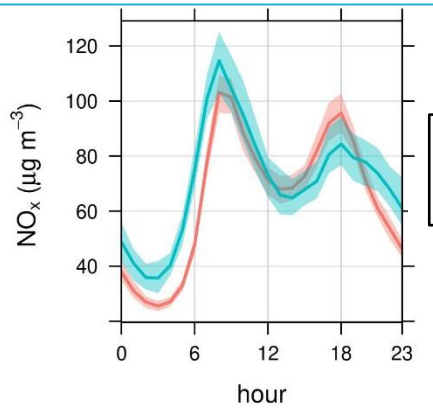


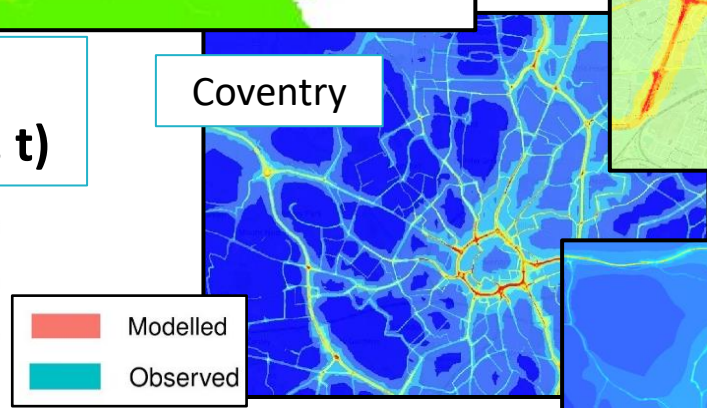
High resolution at urban scale

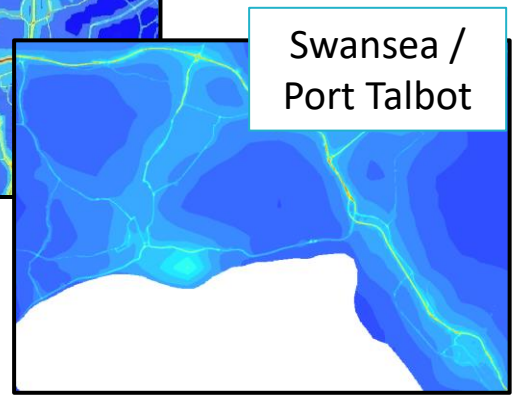


Evaluation of hourly concentration data C (x, y, z, t)

Example outputs from case studies







Length scales differ

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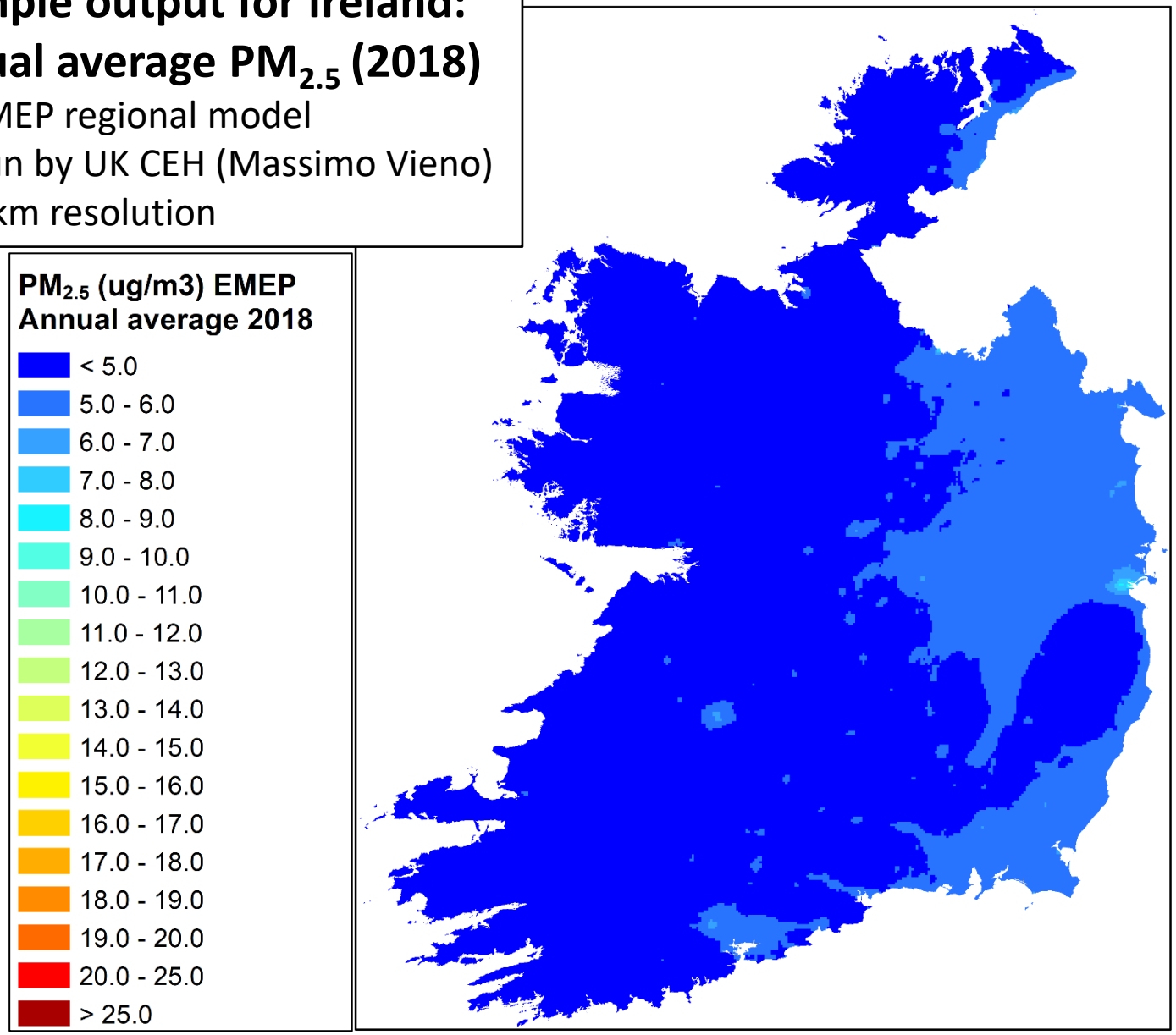
What are regional chemical transport models?

- 1 km grid resolution or coarser
- Use spatially and temporally varying meteorology from mesoscale meteorological models (e.g. WRF, UM)
- Model chemical and deposition processes
- Model stagnated flows
- Useful for modelling air quality at background sites, not roadside
- Examples include: EMEP, CMAQ, CAMx, CHIMERE, LOTOS-EUROS, WRF-Chem, AQUM
- Significant computational resources required via High Performance Computers (HPC) or Virtual Machines. Run on Linux operating systems

Example output for Ireland:
Annual average $PM_{2.5}$ (2018)

- EMEP regional model
- Run by UK CEH (Massimo Vieno)
- 1 km resolution



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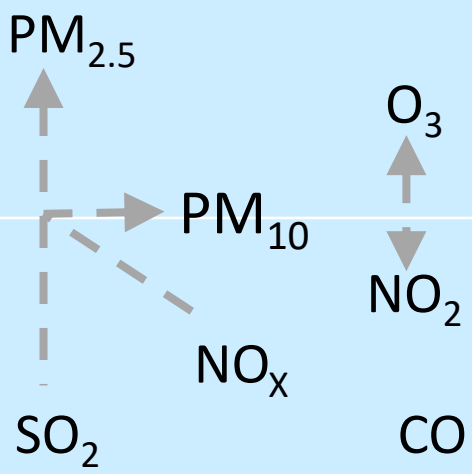
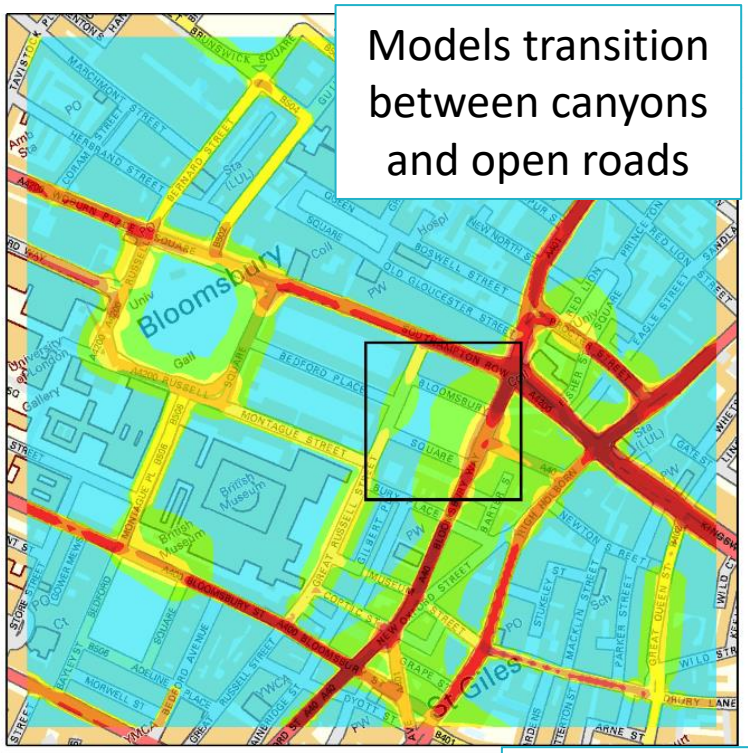
Motivation to link local models with regional models

Chemical interdependencies

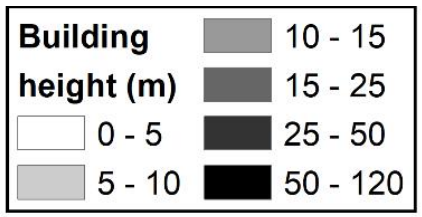
Model type	Spatial scale	Pollutants	Main drivers	Influence of chemical reactions	Temporal scale
Regional	Large (many 100 km)		**Regional** emissions & meteorology	**Longer** timescale reactions e.g. generation of secondary PM	Hours to days
Local	Small (metres to many km)		**Local** emissions & meteorology	**Shorter** timescale reactions e.g. NO_X chemistry	Seconds to hours

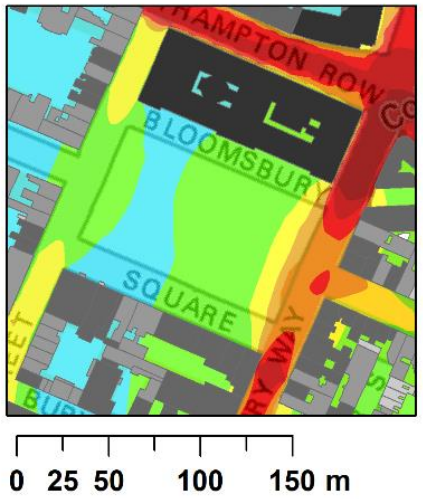
- Dispersion of primary local emissions influences regional pollutant concentrations e.g. domestic & commercial combustion, industrial processes, non-exhaust PM
- When modelling large domains, systems that couple regional and local models are necessary to capture all dispersion and chemical processes at the relevant scales

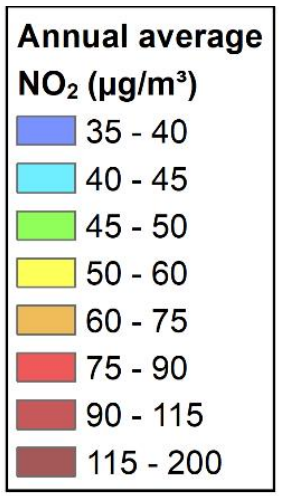
Urban AQ modelling: roadside to urban background



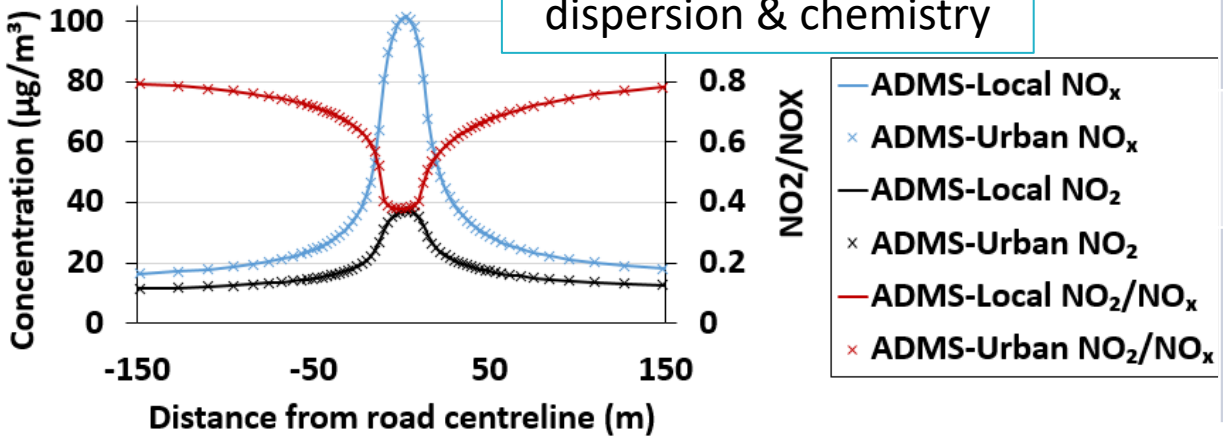
Models transition between canyons and open roads







Models near-road dispersion & chemistry



- **ADMS-Local** model formulation consistent with ADMS-Urban for open road source dispersion
- Simplified approach to modelling street canyons: parameterised canyon method, derived from multiple runs of **ADMS-Urban** Advanced Canyon module
- MAQS works with **ADMS-Local** (road sources only) or **ADMS-Urban** (all source types)

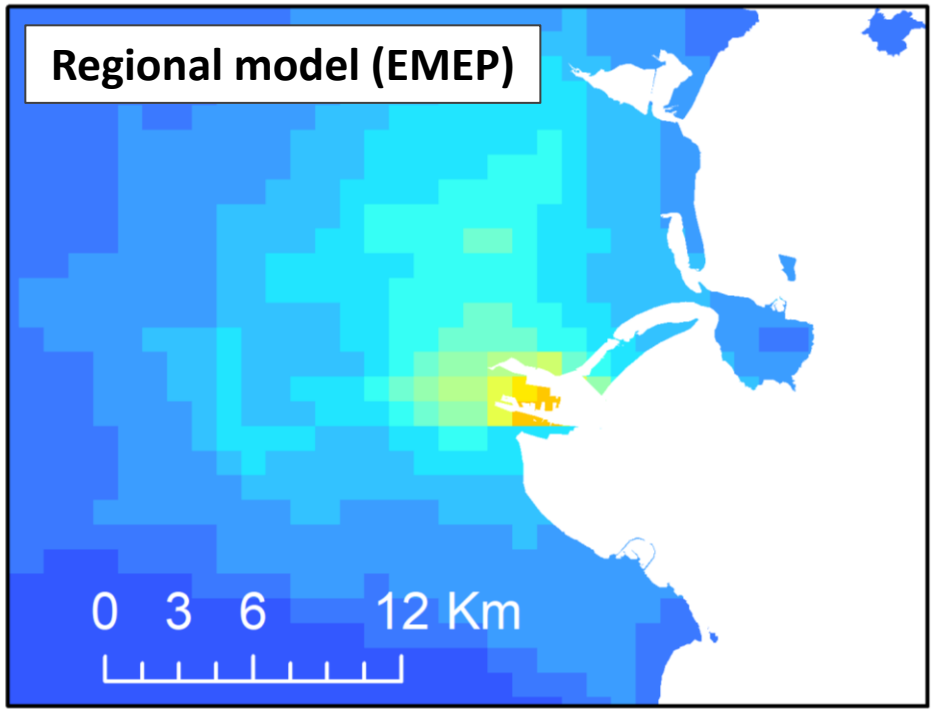
Seaton et al. 2022: A Multi-Model Air Quality System for Health Research: road model development and evaluation. *Environ. Mod. & Soft.* ***155***

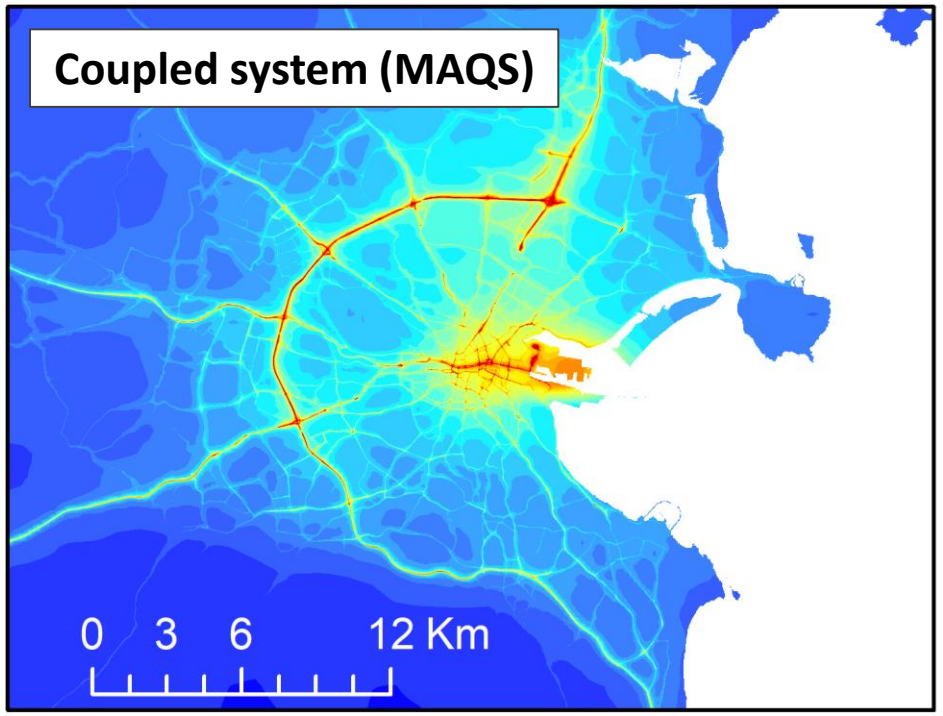
Study	Purpose
Comparison with ADMS-Urban: NO_x, NO_2	To ensure consistency with ADMS-Urban open roads, including chemistry
TRAPOS: NO_x (Hood et al. 2021)	To test performance of parameterised canyon approach
London 2012: NO_x, NO_2, O_3, $PM_{2.5}$, PM_{10} (Hood et al. 2018)	To test city-scale modelling of open roads, canyons, volume source modelling, and chemistry

Country-wide AQ modelling: roadside to rural

- Example: Regional-to-local scale air quality modelling for Ireland (2018, 2019). Project involved evaluation against measurements & health-related Air Quality Standards Regulations 2011 threshold calculations (*local model ADMS-Urban*)
- Pollution maps of the whole of Ireland look similar between regional model and the coupled system
- City-scale maps show improved resolution of coupled system compared to Regional model
- **Strong pollutant concentration gradients are associated with locally modelled sources:**
  - **Road** traffic signature differs by pollutant: relatively NO_2 > PM_{10} > $PM_{2.5}$
  - **Non-road sources** (e.g. domestic combustion) can be modelled at high resolution *if emissions data are available*

Annual average NO_2 pollution maps – Dublin zoom (2019)





< 2.5
2.5 - 5.0
5.0 - 7.5
7.5 - 10.0
10.0 - 12.5
12.5 - 15.0
15.0 - 17.5
17.5 - 20.0
20.0 - 22.0
22.0 - 24.0
24.0 - 26.0
26.0 - 28.0
28.0 - 30.0
30.0 - 32.0
32.0 - 34.0
34.0 - 36.0
36.0 - 38.0
38.0 - 40.0
40.0 - 50.0
> 50.0

NO_2 µg/m³

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Skipping further details of MAQS

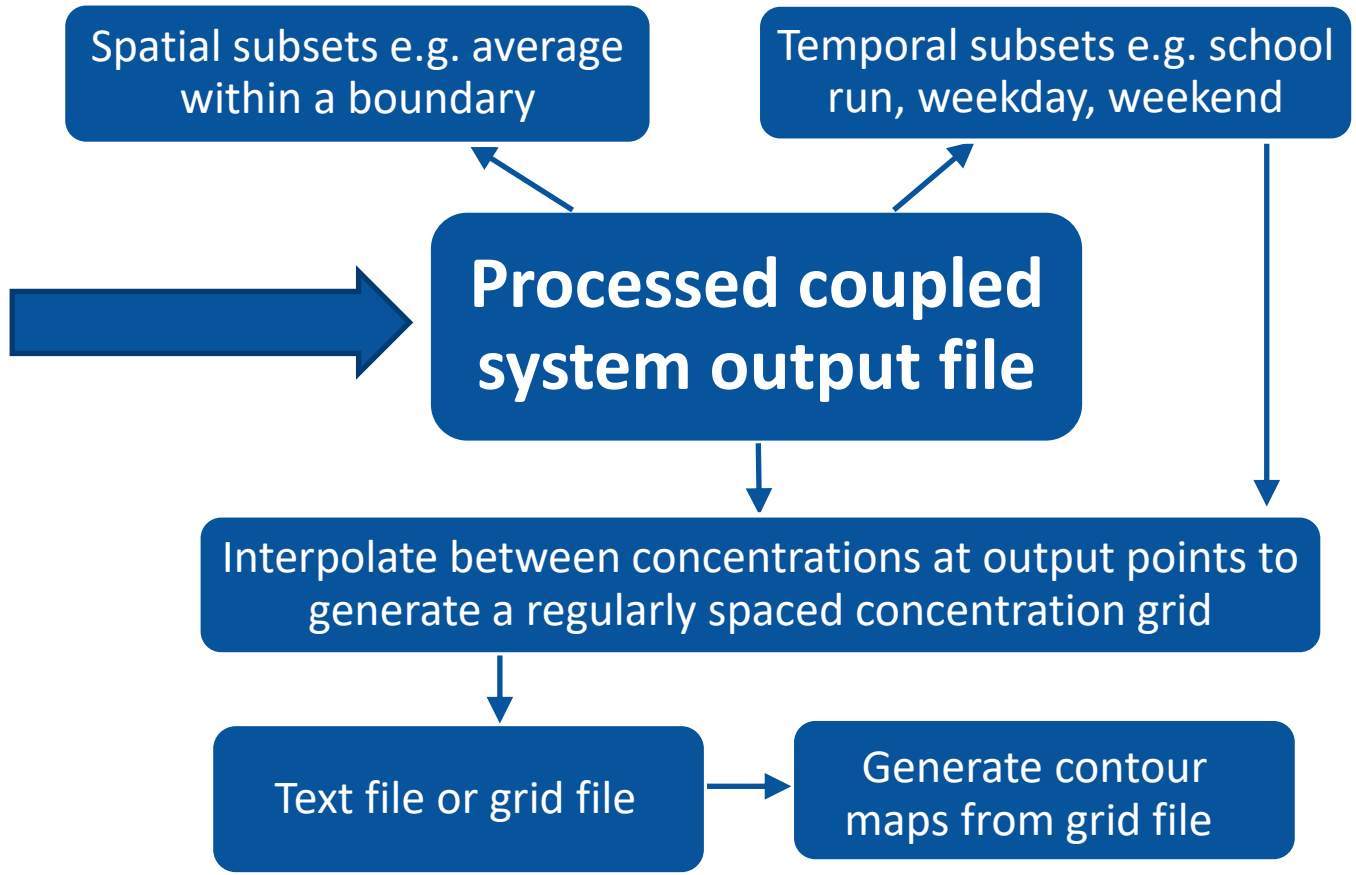
- Concept
- Formulation
- Inputs

Suggestions for further reading provided at end

Coupled system (MAQS) outputs

Raw coupled system output file

- Two types of system runs:
  1. **Receptor** (quick, executes in hours)
  2. **Contour** (longer, executes in days)
- **Variable grid** ADMS-type output file (netCDF format), to resolve concentration gradients near roads
- **Hourly** or annual concentration data for multiple pollutants: NO_x, NO_2, O_3, PM_{10}, $PM_{2.5}$*



** Other pollutants can be modelled where emissions are available & appropriate chemical mechanisms are accounted for in the models*

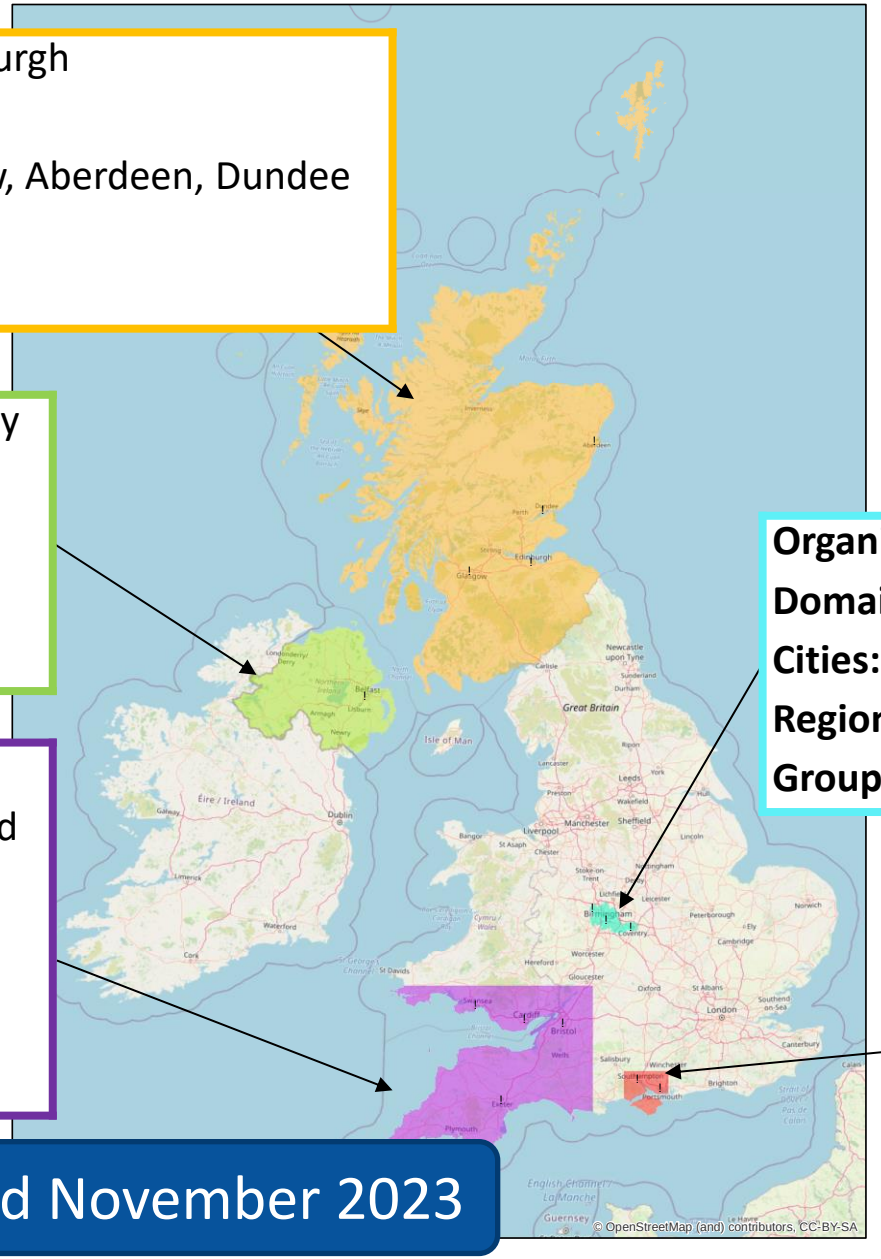
MAQS testing under Clean Air project

Clean Air Programme

Organisation:	University of Edinburgh
Domain:	Scotland
Cities:	Edinburgh, Glasgow, Aberdeen, Dundee
Regional model:	EMEP
Group lead:	Prof Ruth Doherty

Organisation:	Lancaster University
Domain:	Northern Ireland
Cities:	Belfast
Regional model:	WRF-Chem
Group lead:	Prof Oliver Wild

Organisation:	Met Office
Domain:	South-West England & South Wales
Cities:	Exeter, Bristol, Cardiff, Swansea
Regional model:	AQUM
Group lead:	Dr Rachel McInnes



MAQS version 1.2 released November 2023

Modelling groups at **CERC**, the **Met Office** and project partners the Universities of **Birmingham**, **Edinburgh**, **Hertfordshire*** and **Lancaster** beta-tested the system during the MAQS-Health project

Organisation:	CERC
Domain:	United Kingdom
Regional model:	Defra background maps

Organisation:	University of Birmingham
Domain:	West Midlands
Cities:	Birmingham, Wolverhampton, Coventry
Regional model:	CMAQ
Group lead:	Prof William Bloss

Organisation:	University of Hertfordshire
Domain:	Portsmouth and Southampton
Cities:	Portsmouth, Southampton
Regional model:	CMAQ
Group lead:	Prof Ranjeet Sokhi

* Configuration continued as part of EMERGE

Existing MAQS applications and potential uses (1 of 3)

BASELINE

- **National modelling** relative to UK & EU regulations
  - Modelling of Ireland for the Irish Environmental Protection Agency demonstrates MAQS' capability (coupled with EMEP)
  - The Croatian Meteorological and Hydrological Service are currently assessing MAQS' potential for compliance modelling for Croatia (coupled with LOTOS EUROS)
- **Air quality research**
  - Academics at the Department of Meteorology and Geophysics at the University of Sofia, Bulgaria are undertaking research using ADMS-Urban and MAQS to model Sofia (coupled with CMAQ)
  - Academics at the University of Hertfordshire are using MAQS within the EMERGE research project, focusing on shipping in the Portsmouth and Southampton region (coupled with CMAQ)
- **Generation of datasets for use in health research & applications**
  - *No known applications of MAQS to date*
  - Daily 10 m gridded datasets 2010 – 2014 for Greater London *generated using ADMS-Urban* for UCL's 'Air Pollution, housing and respiratory tract Infections in Children: National Birth Cohort Study' (PICNIC)
  - High-spatial and temporal resolution data *generated using ADMS-Urban* aggregated to annual average, ward level concentrations for use in University of Birmingham's Air Quality Lifecourse Assessment Tool (AQ-LAT)* to estimate impacts of $PM_{2.5}$ & NO_2 exposure on morbidity, mortality, and associated healthcare costs in the West Midlands

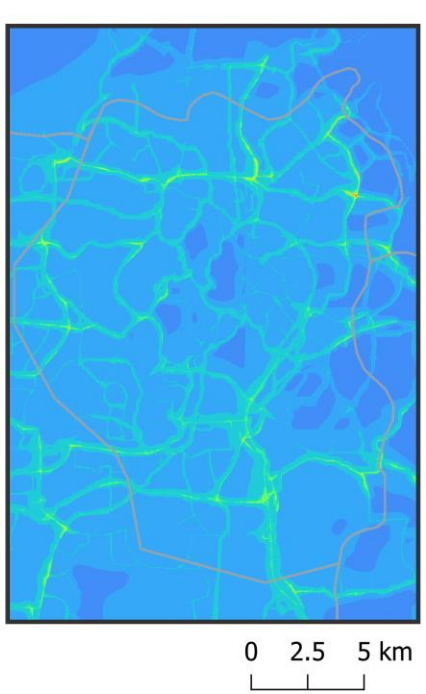
Existing MAQS applications and potential uses (2 of 3)

AIR QUALITY FORECASTING

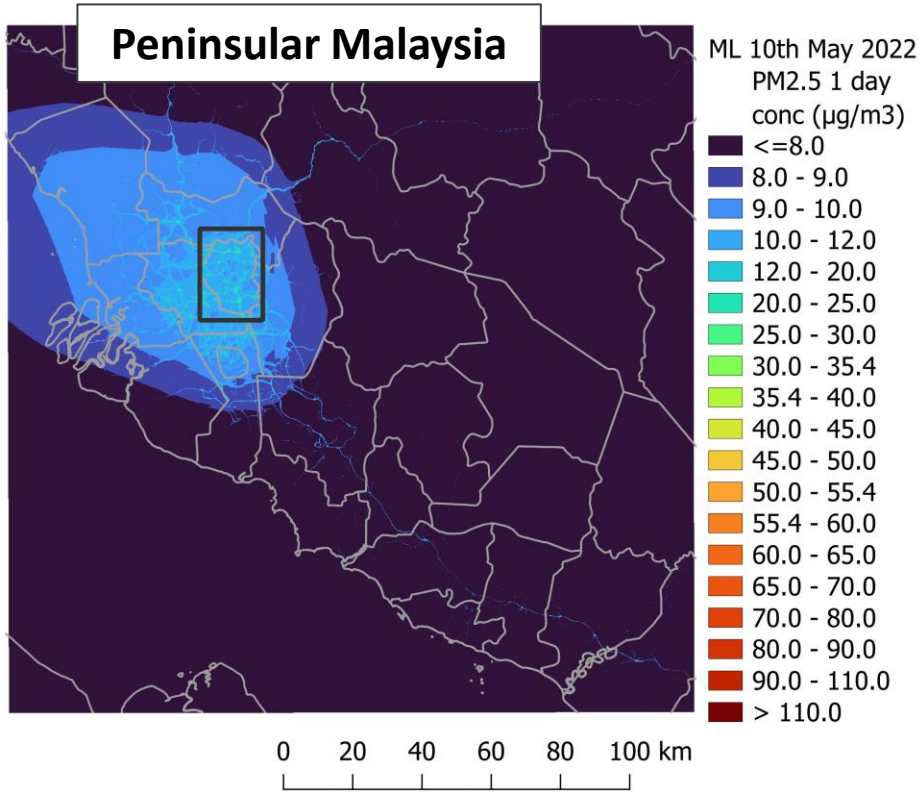
- HKUST run MAQS over Hong Kong for the HK EPD (coupled with CMAQ)
  - Personalised AQ & exposure health risk data available via mobile app

Hong Kong

- Demonstration of High-resolution Air Quality forecasting in South East Asia
  - MAQS applications in Vietnam & Malaysia (coupled to CAMS)



Peninsular Malaysia



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CERC

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VIET NAM NATIONAL UNIVERSITY HO CHI MINH CITY

UK International Development Partnership | Progress | Prosperity

Existing MAQS applications and potential uses (3 of 3)

SOURCE APPORTIONMENT

- *Regional-to-local scale source apportionment (SA) possible if regional model has SA feature, or use "brute force" (no example applications currently)*

SCENARIOS (include baseline modelling)

- *Coupled system can be used to assess scenario impacts where the regional and local models use consistent scenario emissions*
- 5-year initiative to decarbonise road transport (West Midlands, South Wales, and the Great Lakes megaregion of the US) by the 'Global Centre for Clean Energy and Equitable Transportation Solutions' (CLEETS) – Universities of Birmingham and Cardiff working with partners from the US on transport scenarios (coupled to WRF-CMAQ)
- Economic and health outcomes of road building in the Punjab region of Pakistan (research by MIT, LSE and Sciences Po): baseline and counterfactual air pollution modelling and analyses (coupled to CAMS)
- Assessment of the impact of implementing regional and local traffic and industrial source pollution mitigation scenarios on a range of toxic air pollutants, including ozone in Guangzhou, China (coupled to CMAQ)
- CERC have designed an extended coupled modelling system "MAQS-Scenario" for scenarios linking Defra Background maps to ADMS-Urban

Summary

System potential

- MAQS is a powerful system that links regional models to ADMS allowing regional-to-streetscale air quality modelling
- MAQS can be used for baseline, forecasting, source apportionment and scenario air quality modelling
- MAQS includes a verification system that facilitates evaluation of modelled values against measurements
- **MAQS can generate a wide range of air pollutant concentration datasets and metrics that can be used for health research**

Further reading

- MAQS User Guide www.cerc.co.uk/UserGuides
- Further details of example applications www.cerc.co.uk/MAQS-applications
- Papers presenting MAQS applications:
  - DOI: 10.1504/ijep.2012.051202
  - DOI: 10.5194/acp-18-11221-2018
  - DOI: 10.1007/978-3-031-12786-1_10
  - DOI: 10.1029/2021GH000506
- Recent papers presenting local model evaluation:
  - DOI: 10.1016/j.envsoft.2022.105455.
  - DOI: 10.1080/10962247.2020.1803158
  - DOI: 10.3390/atmos12080983

Thank you for listening

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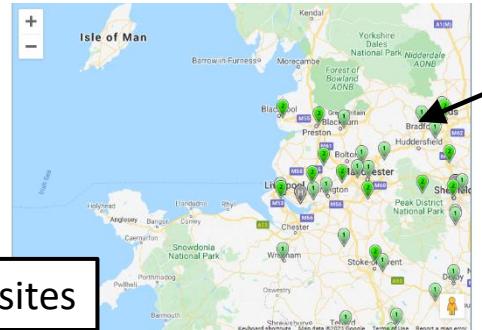
Supplementary slides on data challenges:
- data availability
- large datasets

Data challenges: availability of data

MAQS data requirements

- **Regional model data**
  - Meteorology
  - Gridded emissions
  - Concentrations
  - Surface data
  - Species mapping to local model species
- **Local model data**
  - Road physical properties (width, elevation)
  - Road emissions
  - 3D buildings data or 2D Lidar + building heights
- **Monitoring site information**
  - Network
  - Local authority sites

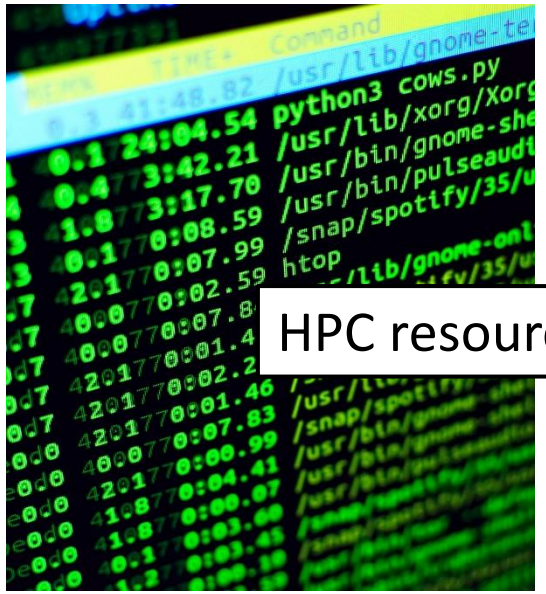


AURN sites

MAQS data challenges

- Relatively few archived regional chemical transport model datasets available, none openly
- Major road traffic emissions not openly available (GB data provided for current project by DUKEMS for 2018)
- Major road traffic network sparse so hotspots may not be identified
- Emissions road network datasets do not include carriageway width information: assumptions required
- 3D building data for calculation of street canyon geometry parameters only available under licence (OSGB data provided for MAQS-Health through Digimap licence for academic partners, and through Met Office for commercial partners)
- Monitor height information incomplete
- No road traffic emissions or 3D buildings datasets available for Northern Ireland

Data challenges: large datasets



- Academics often have access to High Performance Computing (HPC) resources
- CERC use cloud services to run MAQS (Microsoft Azure)
- CERC's code developments have used Linux 'virtual machines', accessible via Windows desktop PCs

Large datasets:
Regional model datasets 100s of GB

System runs

Large datasets:
MAQS contour outputs 100s of GB

Post-processing

Smaller datasets

- Tools have been developed to post-process big datasets into manageable formats, suitable for health research