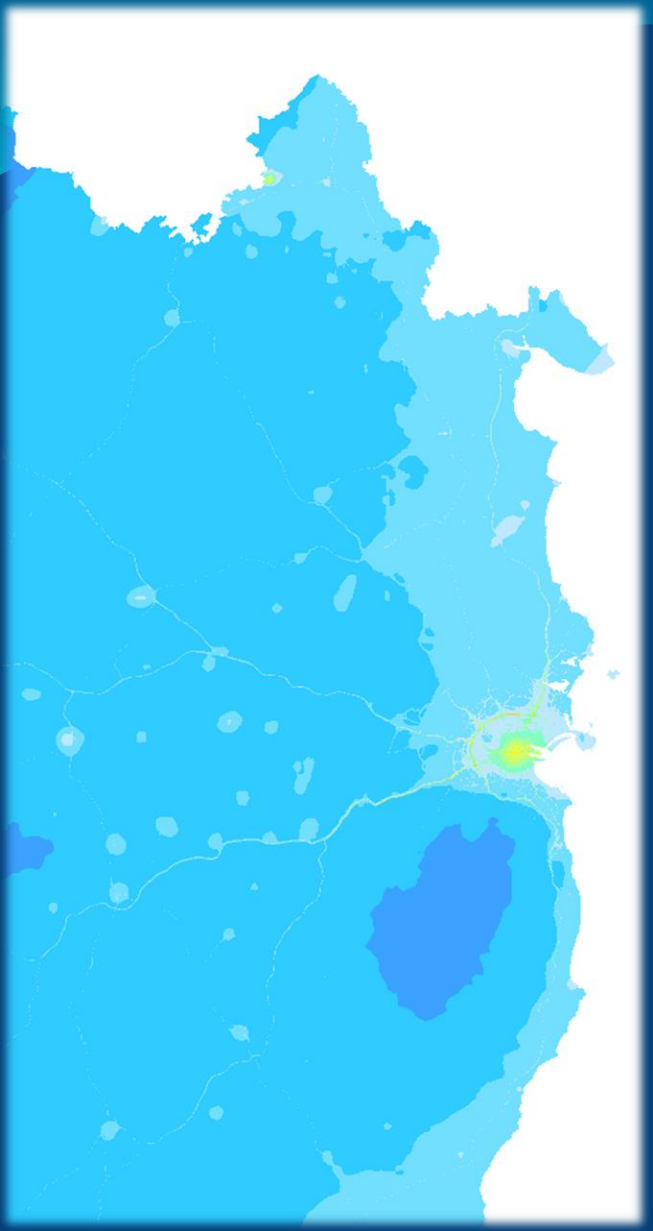


Coupled system modelling: Croatia and Ireland

Jenny Stocker & Darijo Brzoja

ADMS-Urban & ADMS-Roads User Group Meeting

30 November 2023

York

UK CEH

CERC

DHMZ

epa Environmental Protection Agency

Cambridge Environmental Research Consultants
Environmental Software and Services

Outline

- Coupled system:
  - What are regional models?
  - Motivation for Coupled sysem
  - System concept
  - System inputs
  - System outputs
  - Potential uses
- Coupled system application for Croatia: the story so far
- Coupled system application for Ireland: modelling results for 2018 & 2019

ADMS-Urban Regional Model Link (RML)

Multi-model Air Quality System (MAQS)

MAQS-Health for UK Health Research

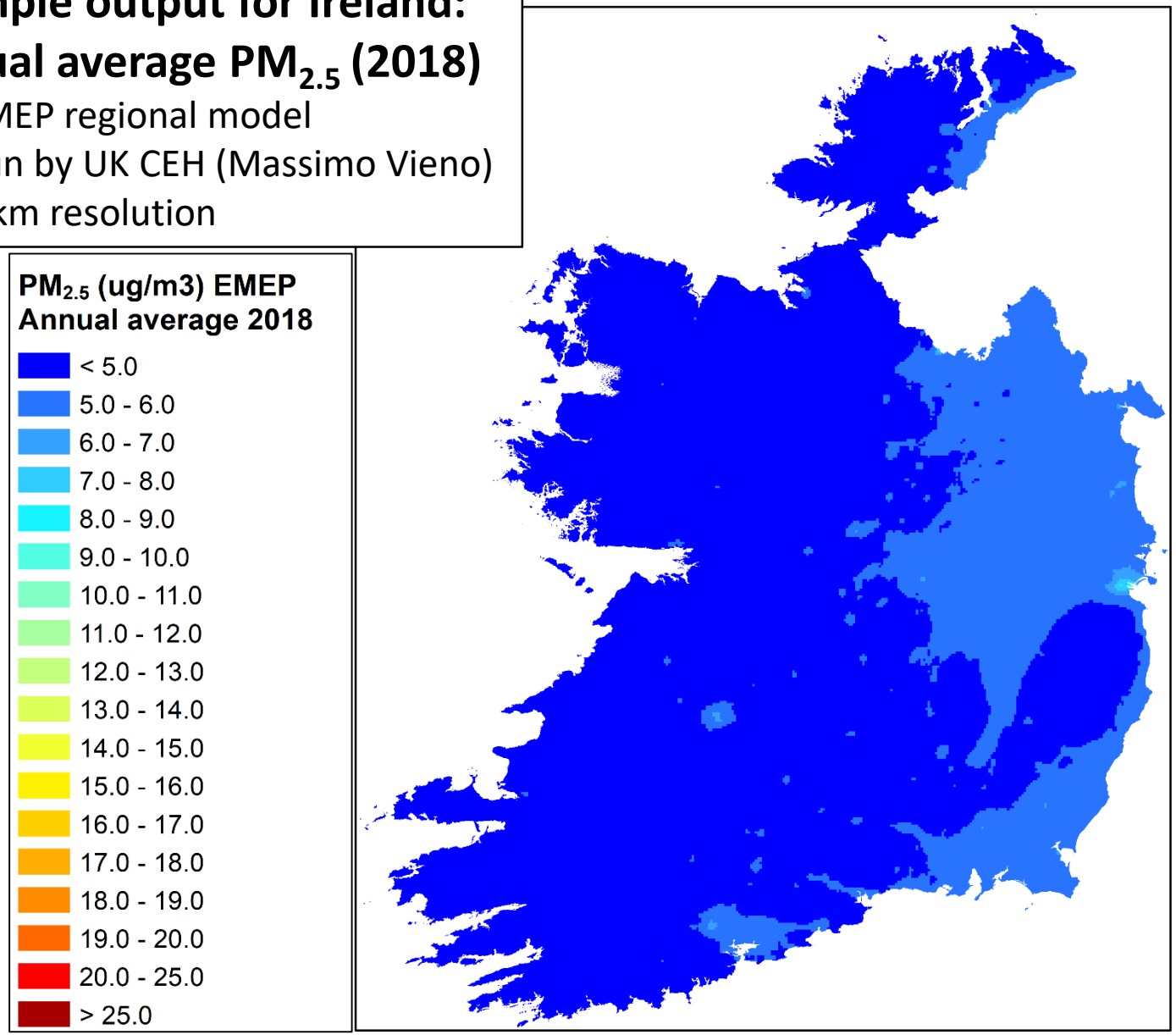
Clean Air Programme

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)
- 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
- Significant computational resources required (High Performance Computers, HPC and Virtual Machines). Run on Linux (not Windows)

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

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



CERC

Coupled system motivation

Chemical interdependencies

Model type	Spatial scale	Pollutants	Main drivers	Influence of chemical reactions	Temporal scale
Regional	Large (many 100 km)	$PM_{2.5}$ O_3 PM_{10} NO_2 NO_X SO_2 CO	**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

Coupled system concept

- **Aim**: to couple local model to regional model without double counting emissions i.e:

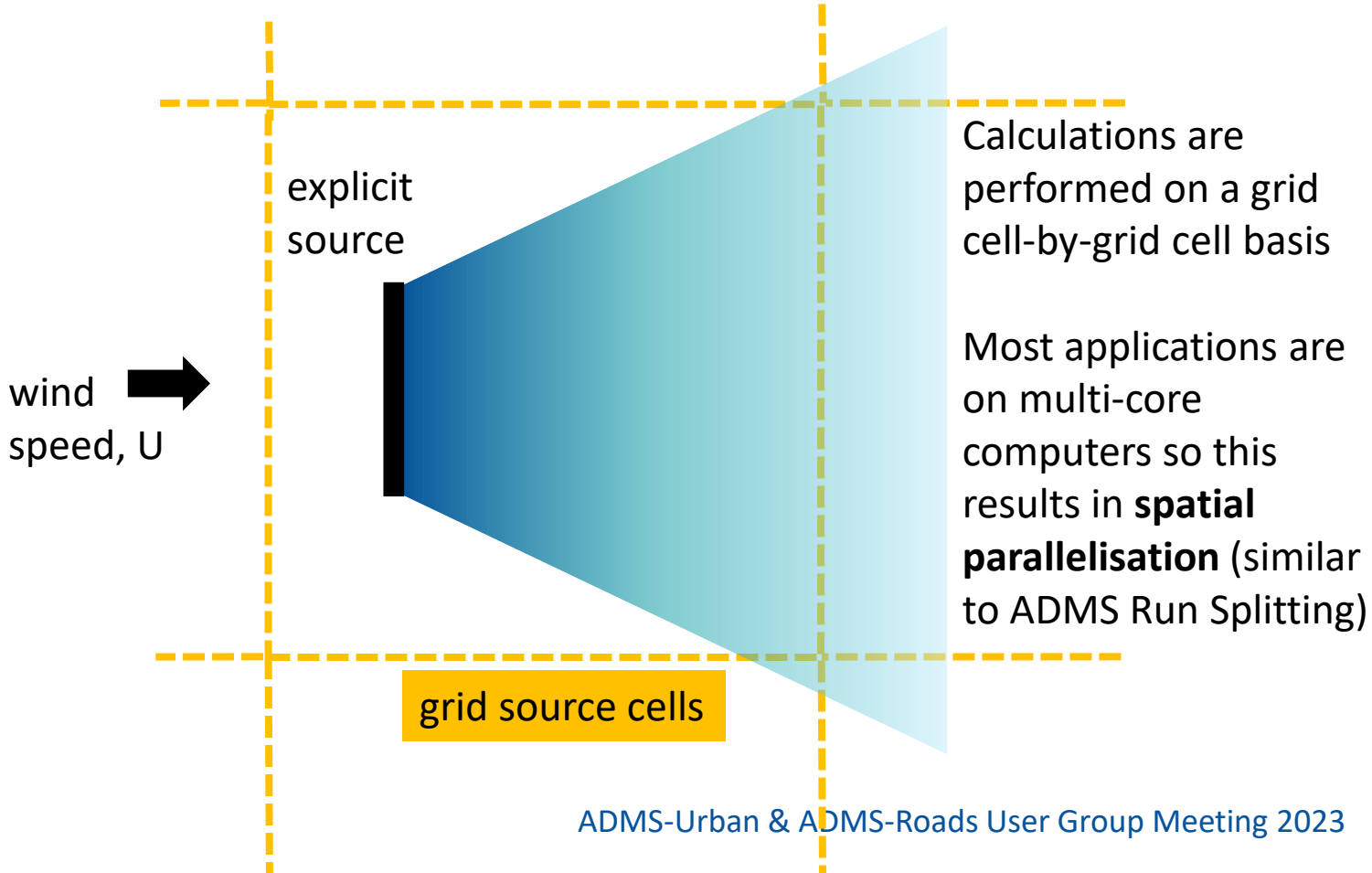
Concentration within nested domain = Regional modelling of emissions - Gridded locally modelled emissions (ΔT) + Explicit locally modelled emissions (ΔT)

Assume

- Plume well mixed in time ΔT
- Meteorology and emissions are slowly varying on time scale ΔT

Use

- Local model for $t < \Delta T$
- Regional model for larger time and hence larger spatial scales



Calculations are performed on a grid cell-by-grid cell basis

Most applications are on multi-core computers so this results in **spatial parallelisation** (similar to ADMS Run Splitting)

Coupled system inputs

Regional model inputs

- Hourly regional chemical transport model data (or Defra Background Maps)
- Hourly emissions data
- Hourly meteorological data

Local model inputs

- ADMS-Urban model input file (.upl) **OR** road source data in text file format
- Gridded site parameters e.g. urban canopy

Other inputs

- System configuration files (text file format control files)

Model set up approach:

- Define domain and projection
- Process regional model inputs into required formats (some supported directly, 3D emissions can be generated from 2D data via EMIT and profiles)
- Develop explicit source emissions (road, points) as for standard ADMS modelling
- Install model (HPC or Virtual Machines)
- Configure system control files

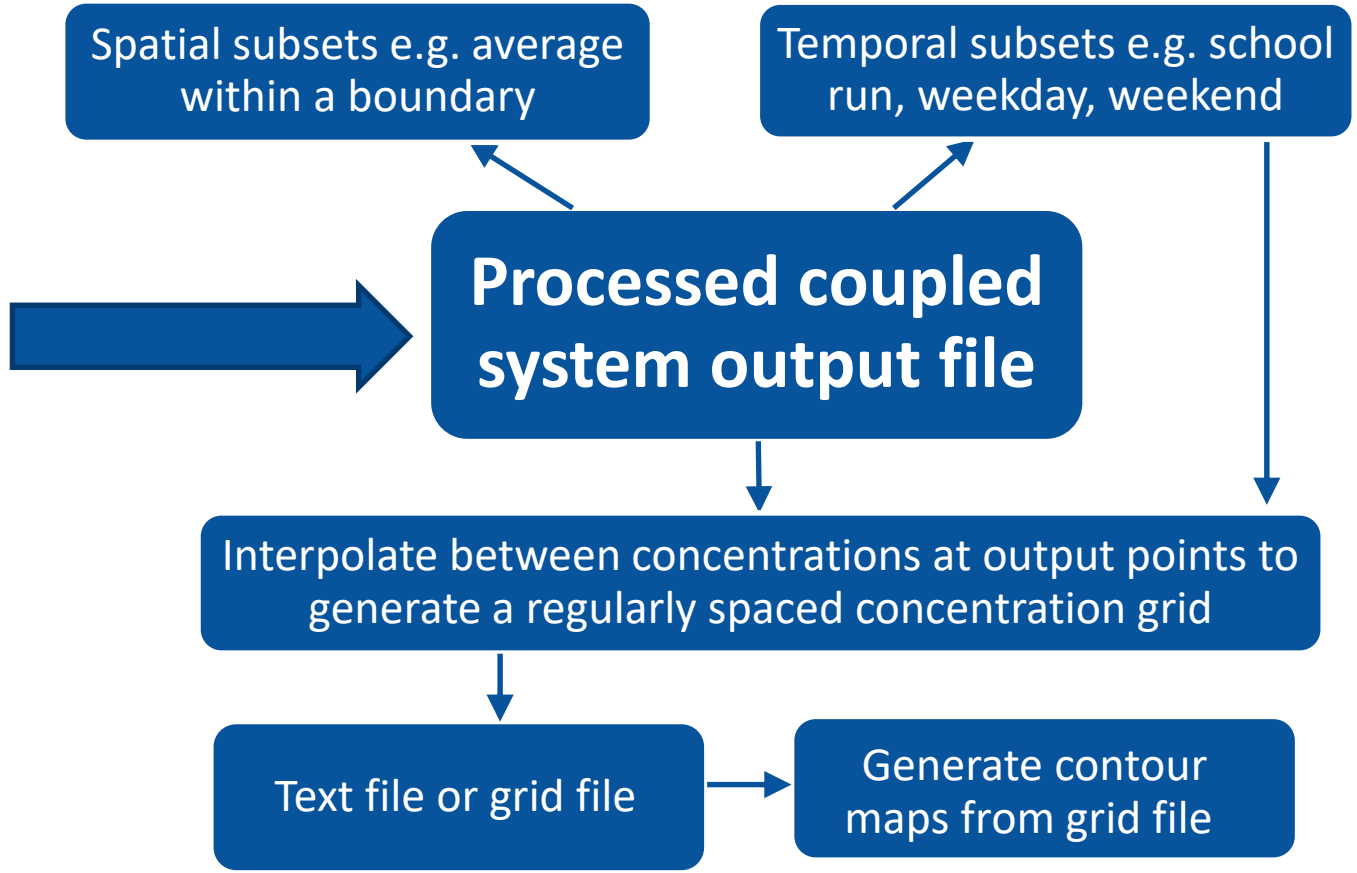
As for other CERC models:

- Comprehensive User Guide
- Training course
- User support

Coupled system 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*

Potential uses

- **National compliance modelling i.e. assessing AQ relative to UK AQSR & EU AQD regulations**
  - Modelling of Ireland for the Irish EPA demonstrates the capability of the system to do this ***Presented later***
  - DMHZ are setting the system up for Zagreb, to assess its potential for compliance modelling ***Details next…***
- **Large spatial scale air quality forecasting systems**
  - Hong Kong University of Science & Technology run the Coupled System within "Praise-HK" for the HK Environmental Protection Department
  - Personalised AQ & Exposure health risk data available via mobile app
- **Scenario modelling to assess the impact of regional policies on local AQ**
  - Coupled system can be used to assess scenario impacts where the regional and local models use consistent scenario emissions
  - CERC have designed a Coupled system for scenarios linking Defra Background maps to ADMS-Urban "MAQS-Scenario"
- **Regional-to-local scale source apportionment (SA) possible if regional model has SA feature, or use "brute force"**

https://praise.hkust.edu.hk/

CERC

THE HONG KONG UNIVERSITY OF SCIENCE AND TECHNOLOGY | PRAISE HK Empower the Public with Personalised Air Quality Information

Coupled system application for Croatia

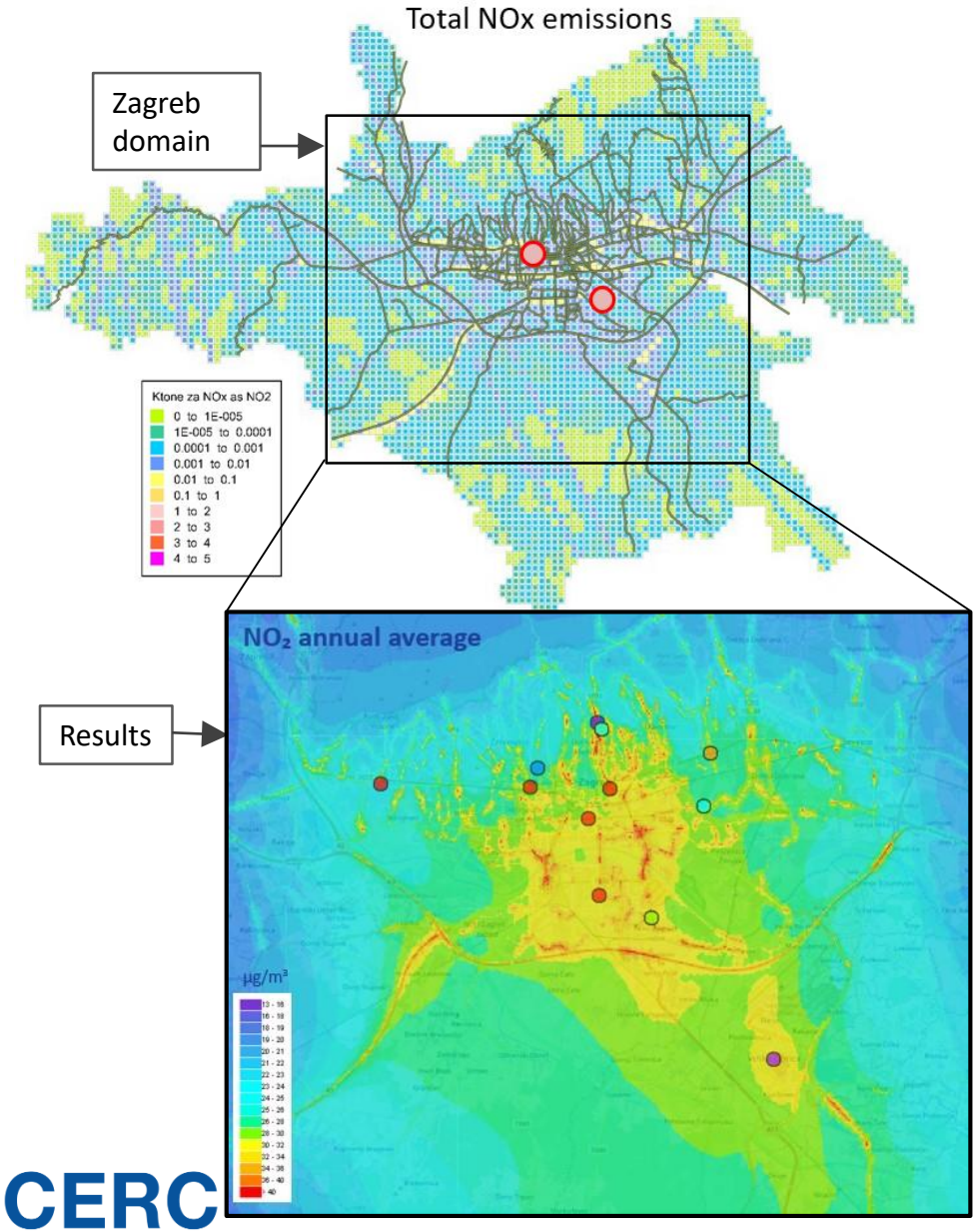
Croatian Meteorological and Hydrological Service

Darijo Brzoja

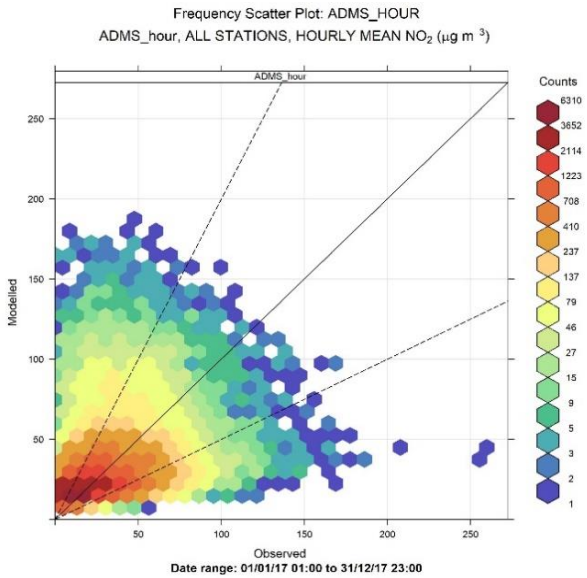
Head of Air Quality Modelling, Research and Implementation Department

Velimir Milić Stipica Šarčević Vesna Gugec

Stand-alone ADMS – Urban modelling in Croatia

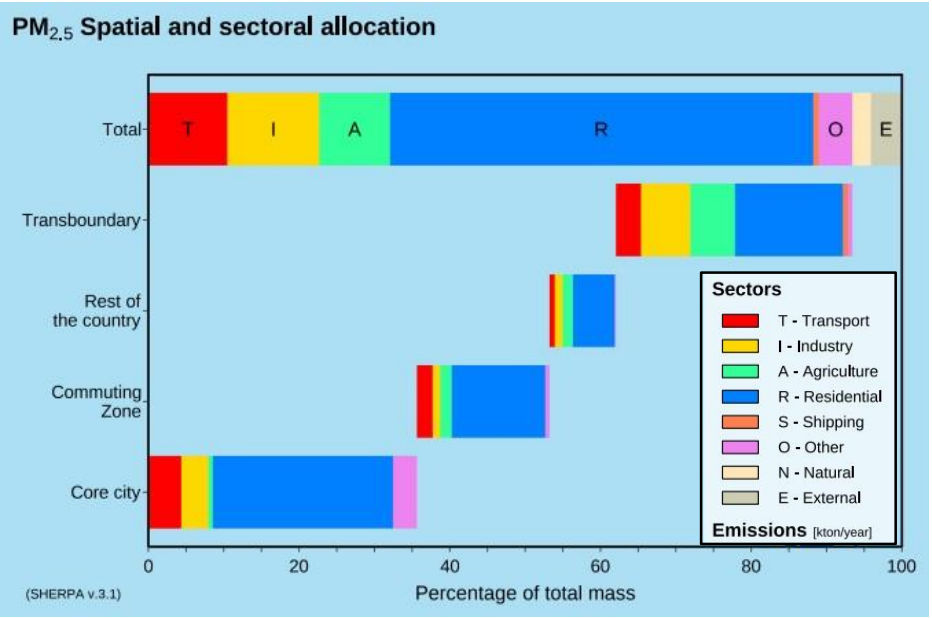


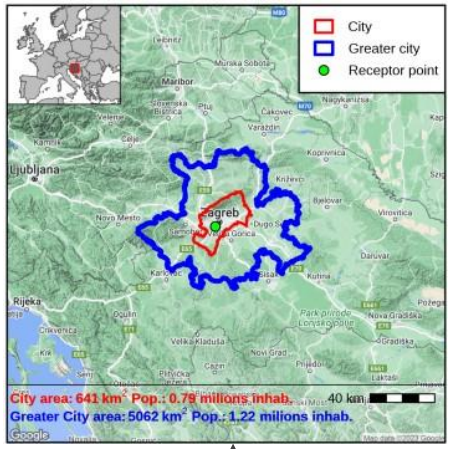
- Modelling for 2017, pollutants: NO_2, PM_{10}
- Emissions inventory provided by Croatian Ministry of Economy and Sustainable Development, 500 m resolution gridded emissions
- Two large point sources, explicit road emissions (expert estimate)
- Coordinate system: HTRS96 Croatia TM (epsg:3765)
- No 3D buildings datasets (no street canyons were modelled)
- Background concentrations: Desinić rural-background site
- Meteorology: Zagreb-Maksimir meteo site (hourly sequential met data)



Coupled system motivation - Croatia

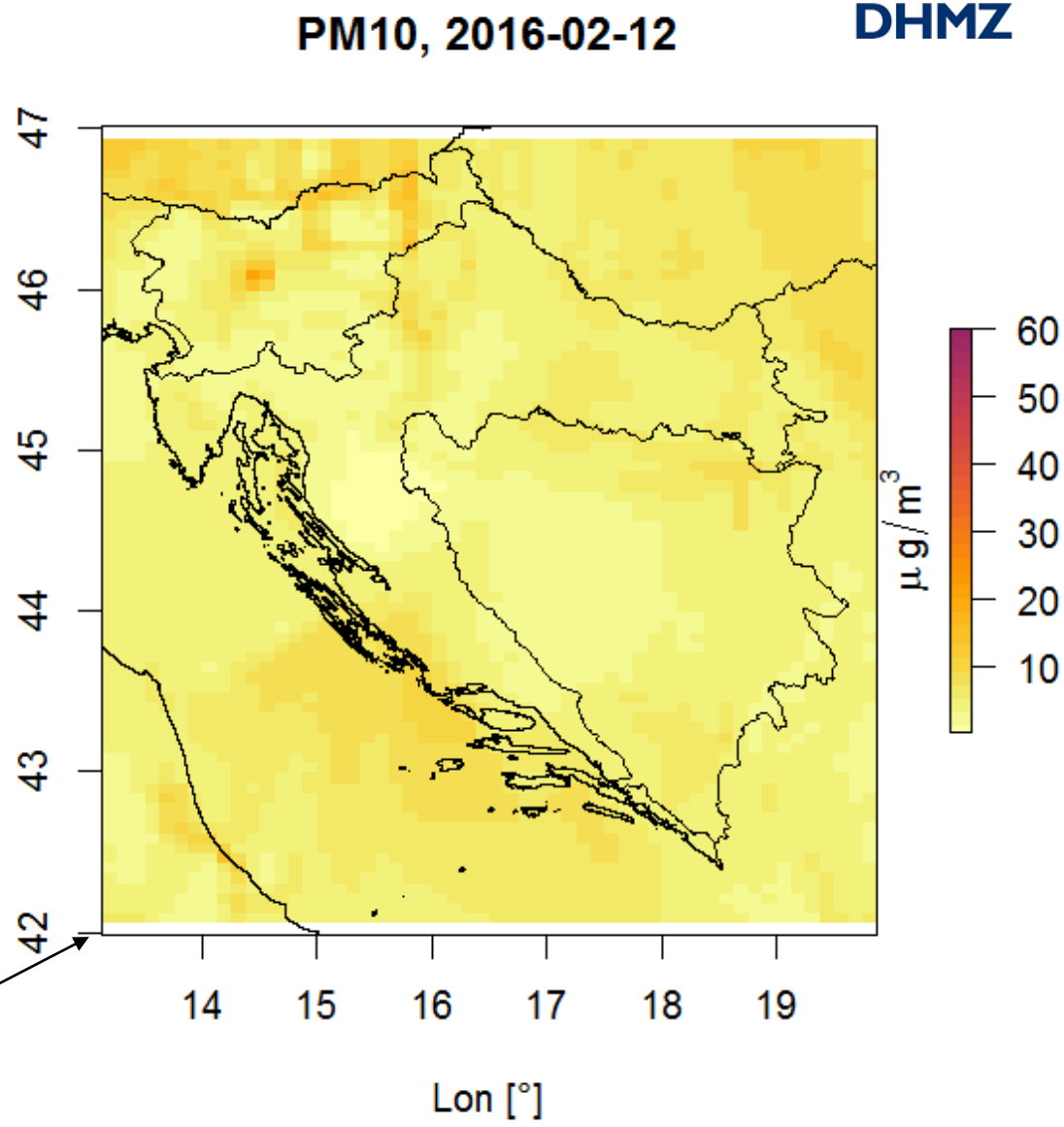
- Large portion of transboundary pollution
- Only one close rural background station (Desinić)





Zagreb

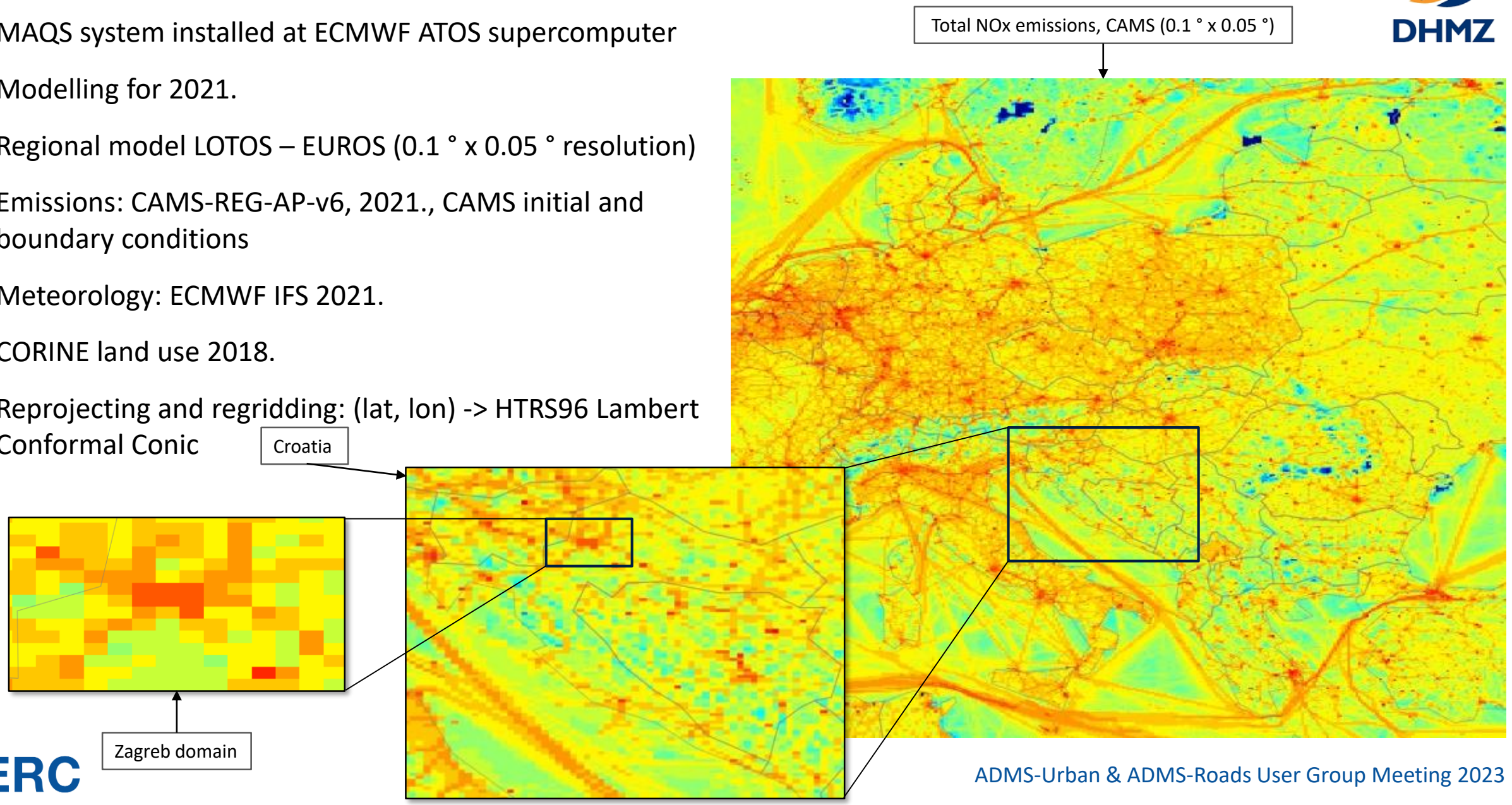
- Core city + Commuting zone: < 55 %
- Transboundary + Rest of the country: > 40 %



LOTOS – EUROS CTM (0.1 ° x 0.05 ° resolution)
Regional contribution to pollution in the city

Coupled system set up and specifics

- MAQS system installed at ECMWF ATOS supercomputer
- Modelling for 2021.
- Regional model LOTOS – EUROS (0.1 ° x 0.05 ° resolution)
- Emissions: CAMS-REG-AP-v6, 2021., CAMS initial and boundary conditions
- Meteorology: ECMWF IFS 2021.
- CORINE land use 2018.
- Reprojecting and regridding: (lat, lon) -> HTRS96 Lambert Conformal Conic

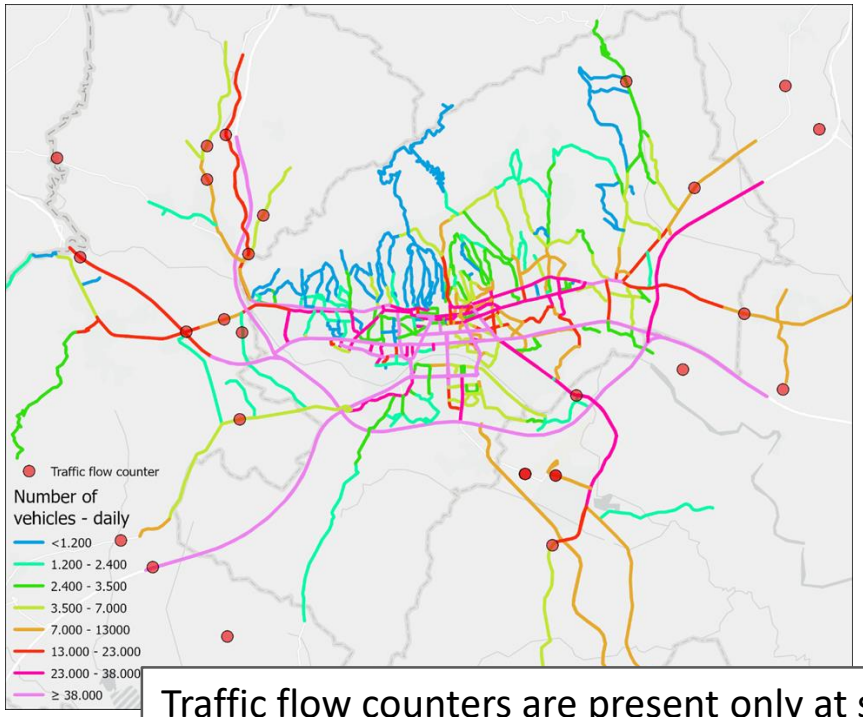


DHMZ

CERC

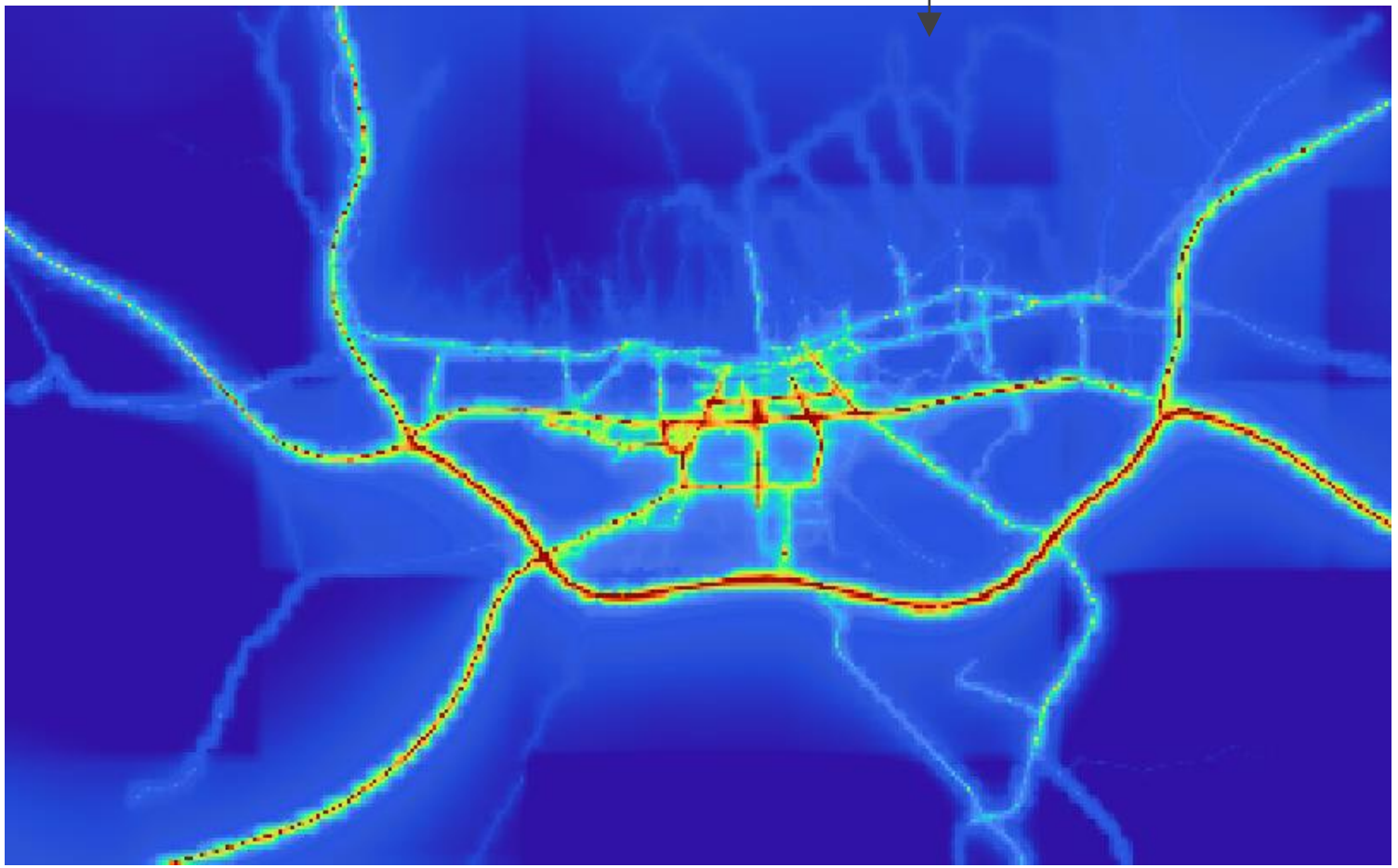
Local model and first results of a coupled system

- ADMS – Urban UPL file contains explicit road emissions
- Road emissions were created using EMIT (emission factors/real-world emissions)
- Road geometry – Open Street Map – processed
- Traffic activity – official traffic counting (state roads & highways)
- Traffic activity in the city – expert assessment



Traffic flow counters are present only at state roads and highways (outside of the city)

First MAQS results
Annual NO_2 concentration



UK CEH

Coupled system application for Ireland

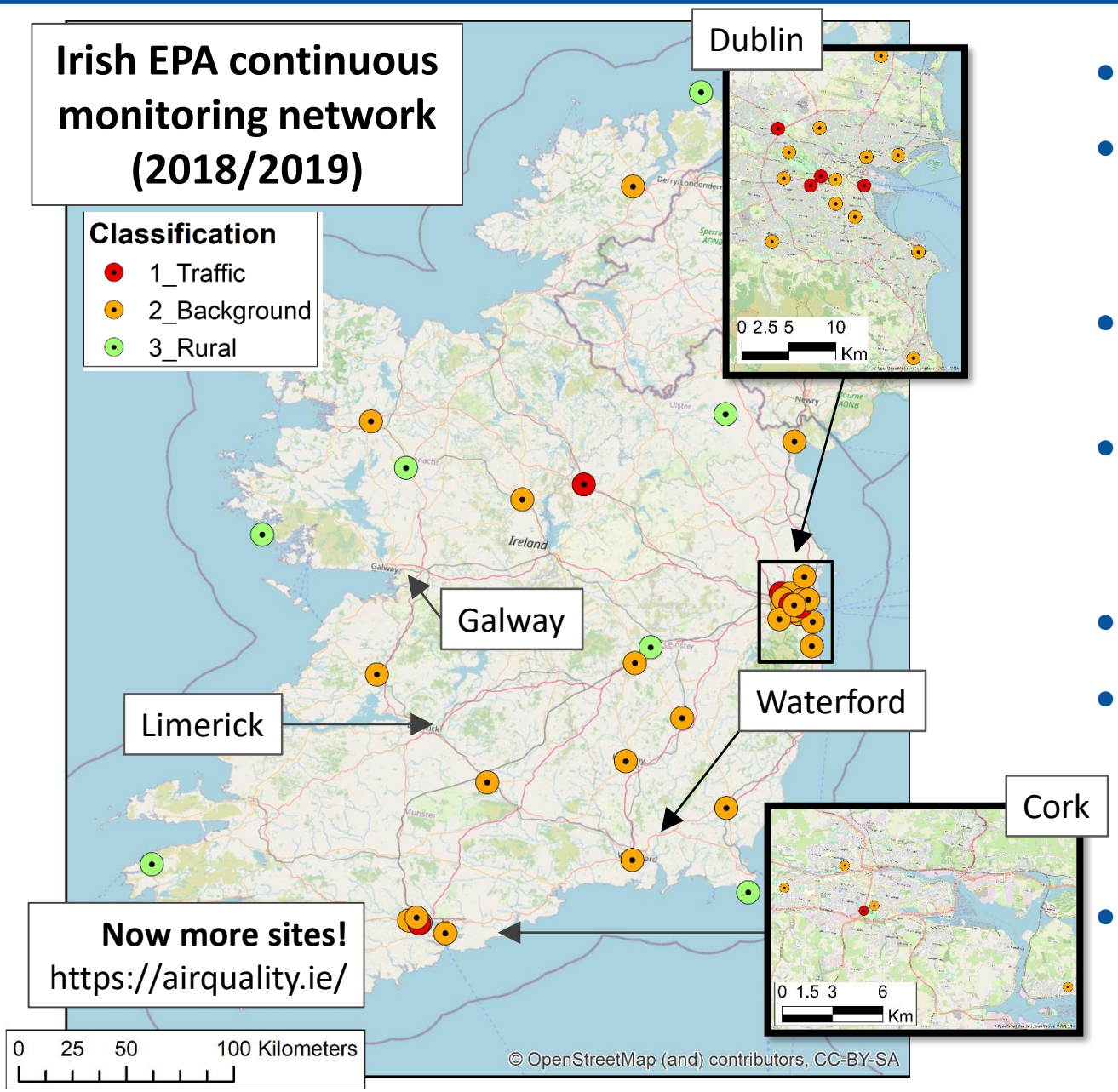
Environmental Protection Agency
An Ghníomhaireacht um Chaomhnú Comhshaoil

National Ambient Air Quality Unit

Kevin Delaney Dermot Burke Patrick Malone David Kelleghan

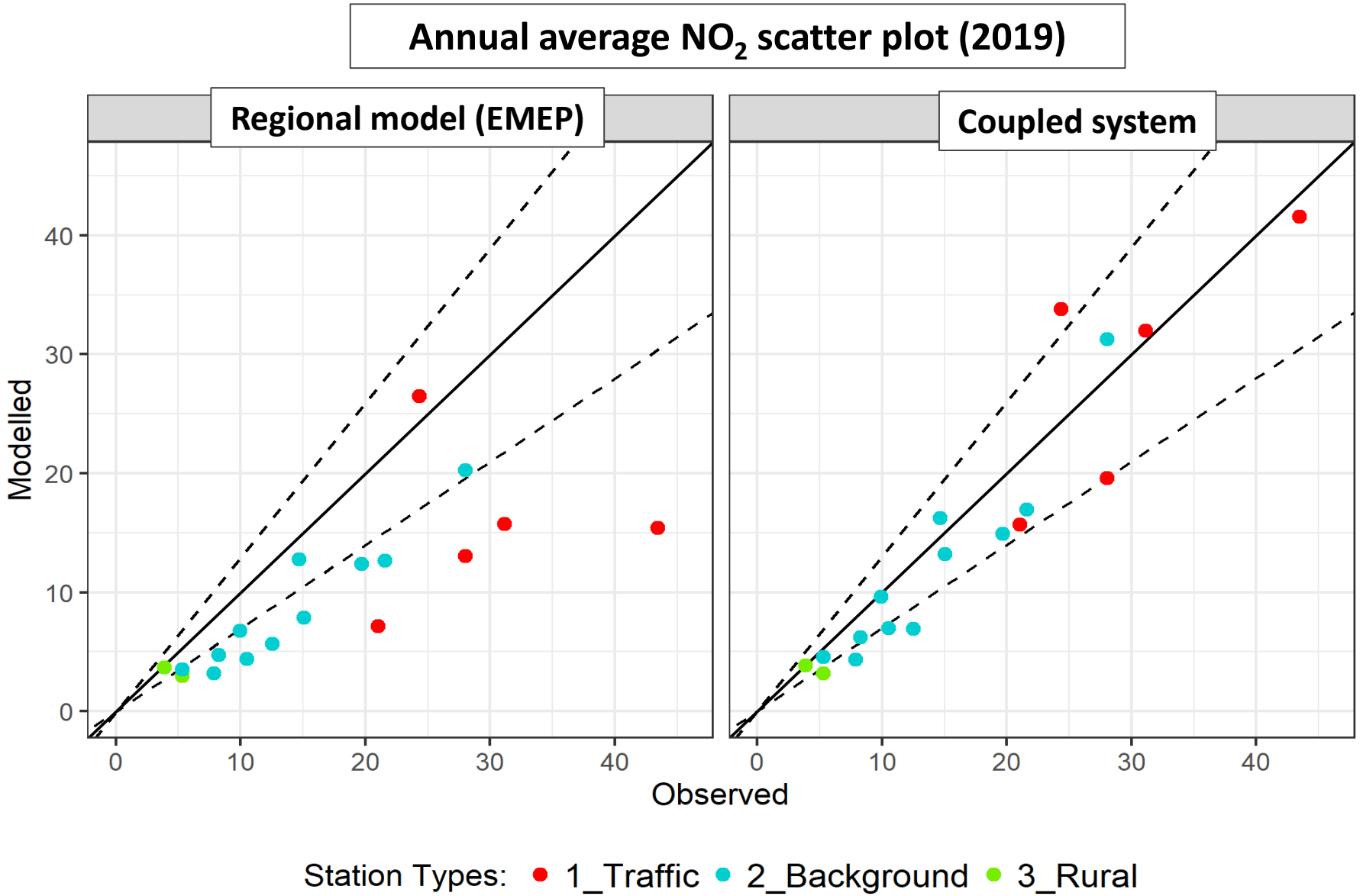
CERC

Summary of Ireland modelling project



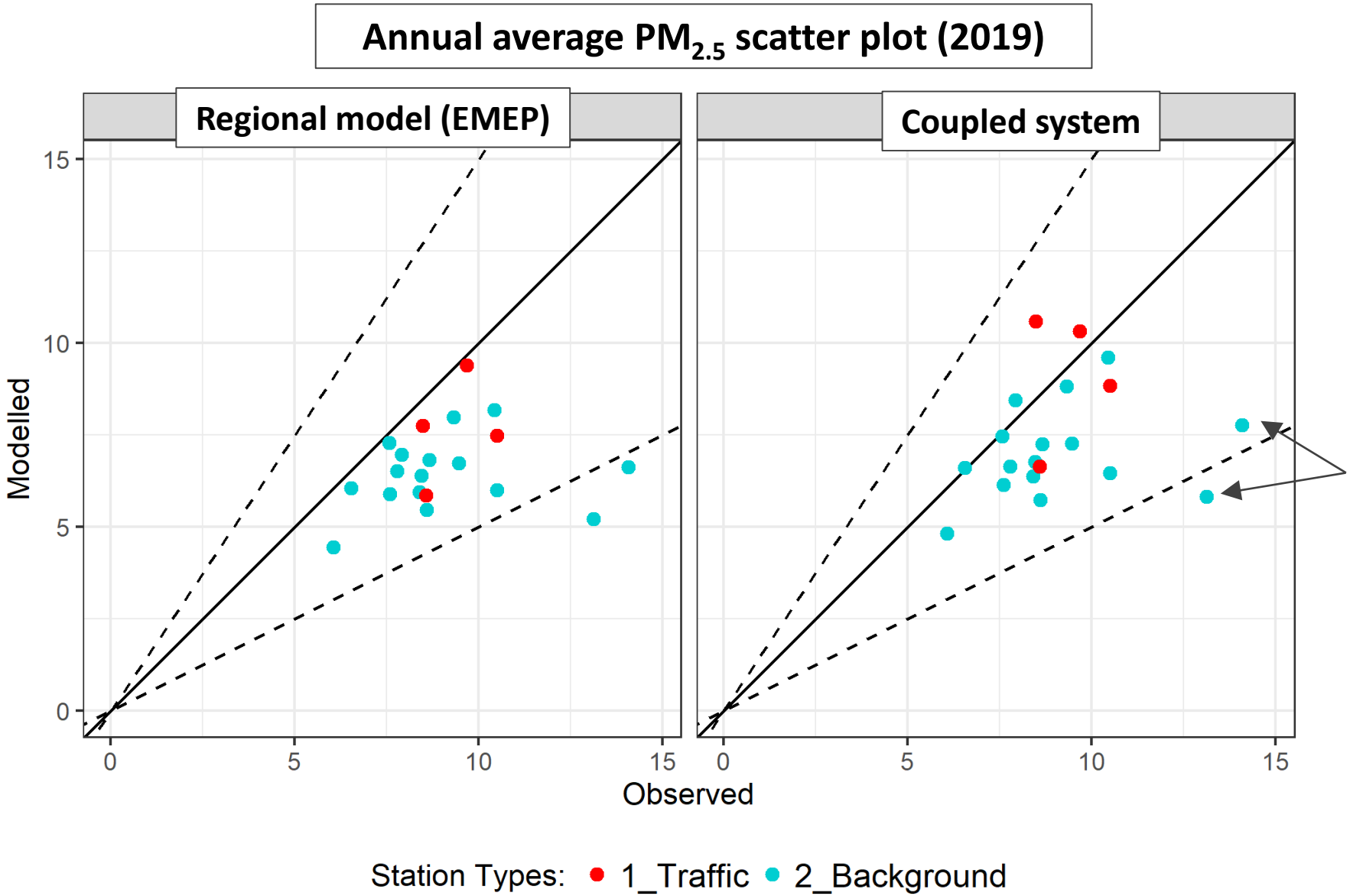
- Modelling for 2018 & 2019
- Emissions inventory derived from MapEIRE, Irish EPA & National Transport Authority data (refer to earlier presentation)
- Regional modelling by UK Centre for Ecology & Hydrology: WRF-EMEP, 1 km resolution
- Generated 3D buildings datasets (Dublin, Cork, Limerick, Galway and Waterford) to derive street canyon and urban canopy datasets
- Modelled NO_2, NO_X, PM_{10}, $PM_{2.5}$ and O_3
- Evaluation:
  - modelled meteorology (wind speed & direction, temperature)
  - all pollutants compared to measurements
- System outputs compared to health-related Air Quality Standards Regulations 2011 (AQSR) thresholds

Evaluation (1 of 3)



- Regional model under-predicts at background and traffic sites due to resolution
- Coupled system gives good agreement at all sites
- Coupled system captures full range of concentrations
- Similar results for 2018 and high percentiles

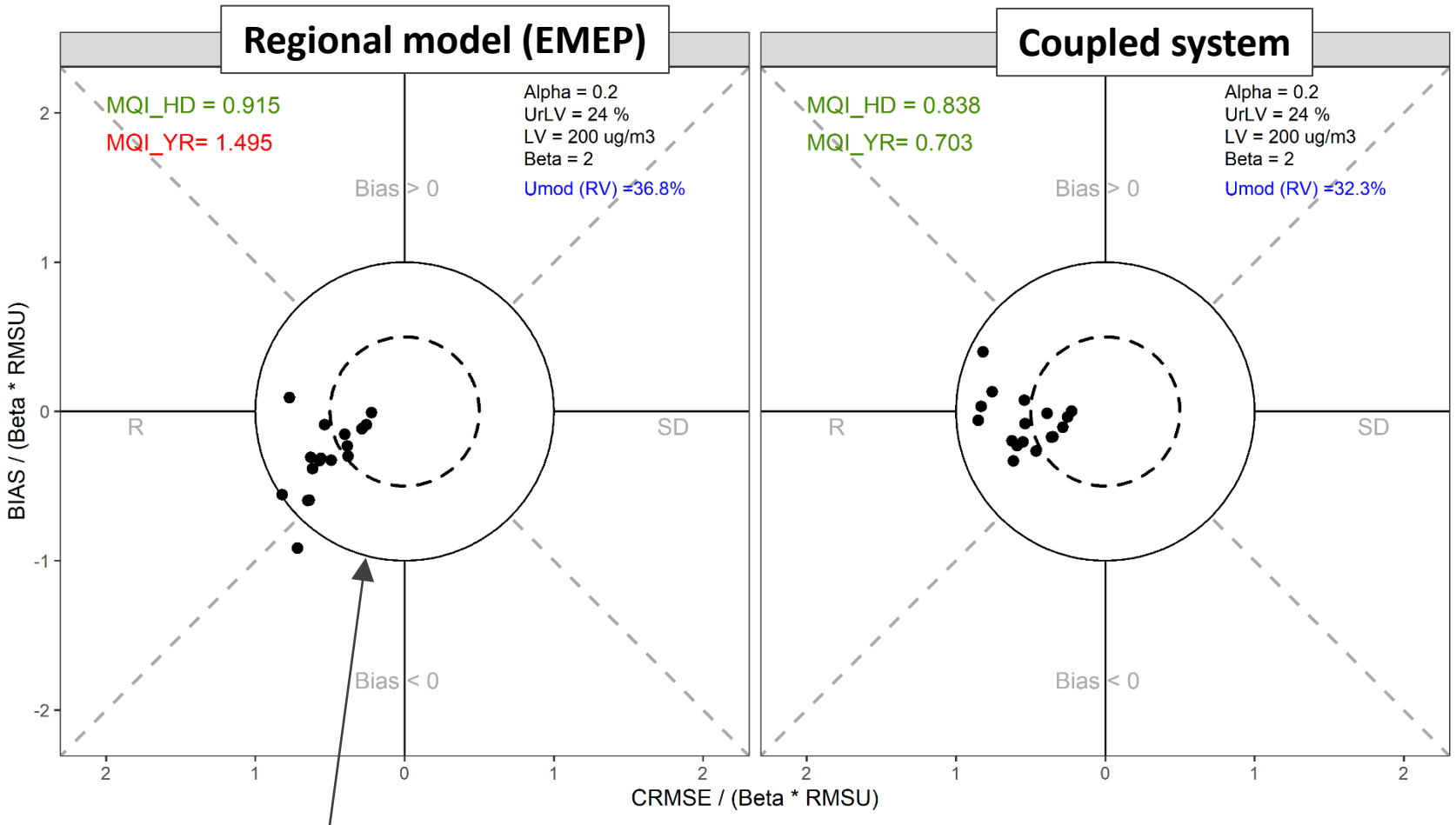
Evaluation (2 of 3)



- Regional model performs generally well at all sites because $PM_{2.5}$ dominated by regional transport
- Coupled system improves agreement at majority of sites
- Two outliers likely influenced by sources unresolved in the emissions inventory e.g. residential solid fuel burning

Evaluation (3 of 3)

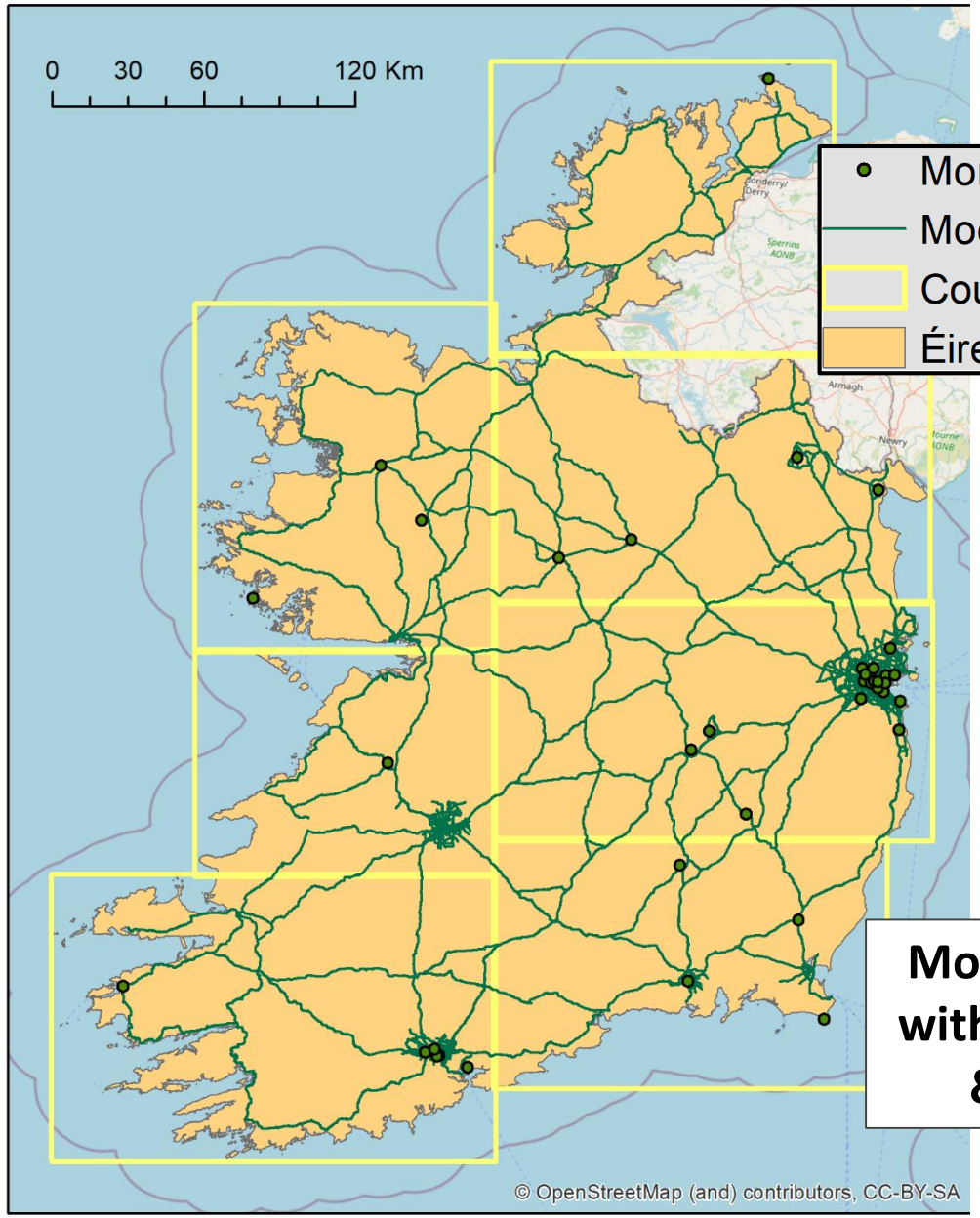
Target plots (annual average NO_2)



90% of points need to be inside the "Target" to achieve the hourly objective

- Model data quality objectives are being proposed as part of the revision to the EU Air Quality Directive. They are based on FAIRMODE Model Quality Indicators and Objectives
- Model data quality objectives achievable by regional models for $PM_{2.5}$, PM_{10} & O_3
- Local-scale modelling usually required to achieve NO_2 objective
- CERC's **Model Evaluation Toolkit** generates Target plots as well as multiple other graphs and statistics (see Rose Jackson's 2022 UGM talk)

Running coupled system to generate pollution maps



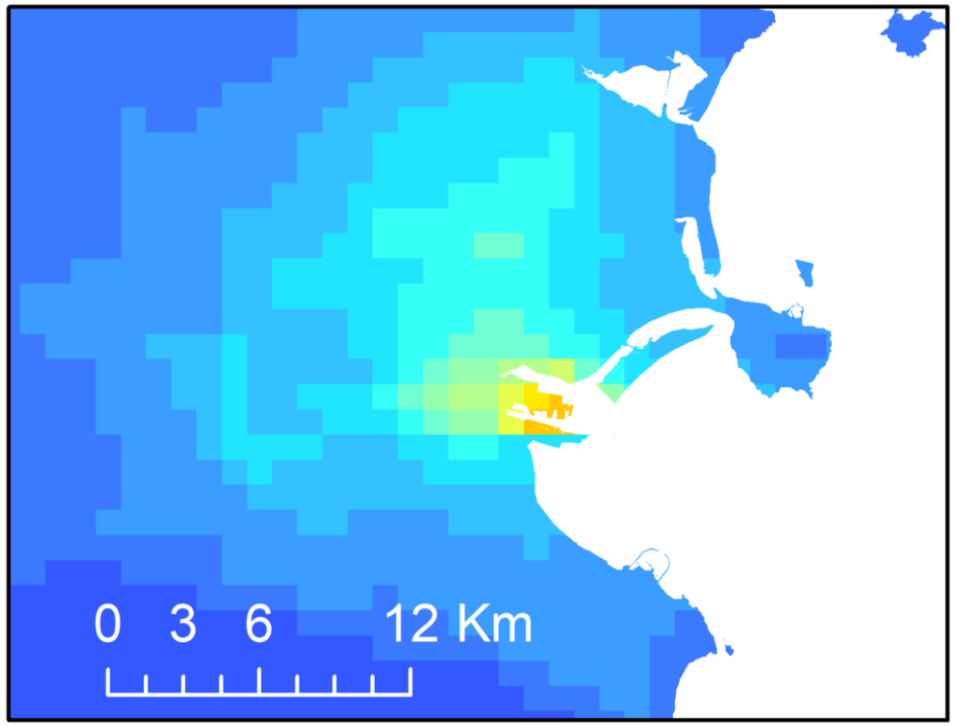
Modelling sub-domains, with major road network & monitoring sites

- Domain split into 7 sub-domains:
  - Increase run time efficiency
  - Facilitates large file transfer & storage
  - Separate emissions database files for each sub-domain
- System run on a 4 Virtual Machines, each with 48 cores.
- Computer resource costs non-negligible (few thousand £)

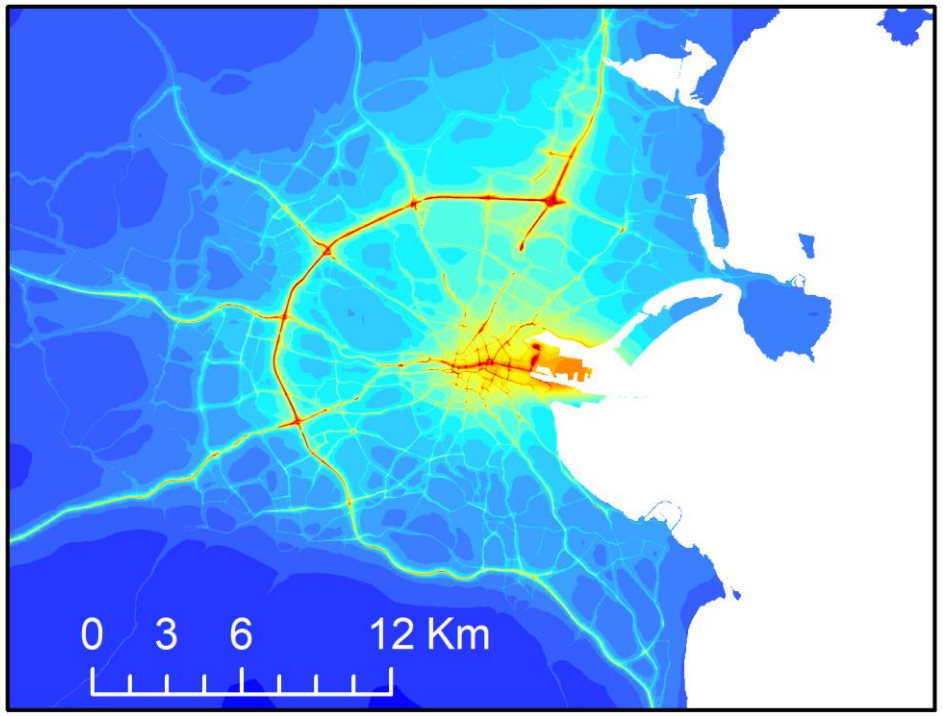
Pollution maps (1 of 3)

- 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

Regional model (EMEP)



Coupled system

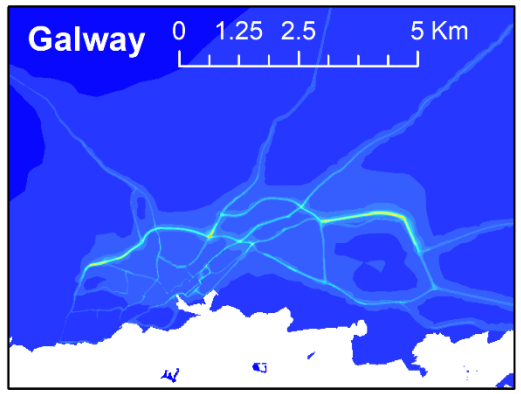


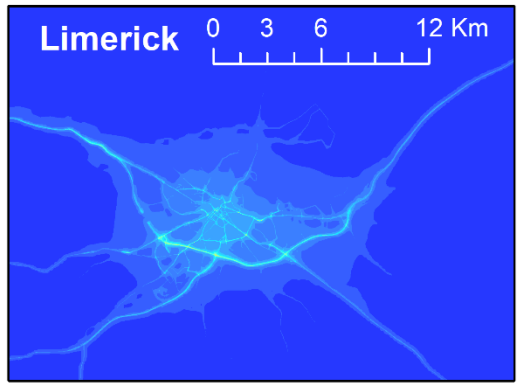
NO2 µg/m³

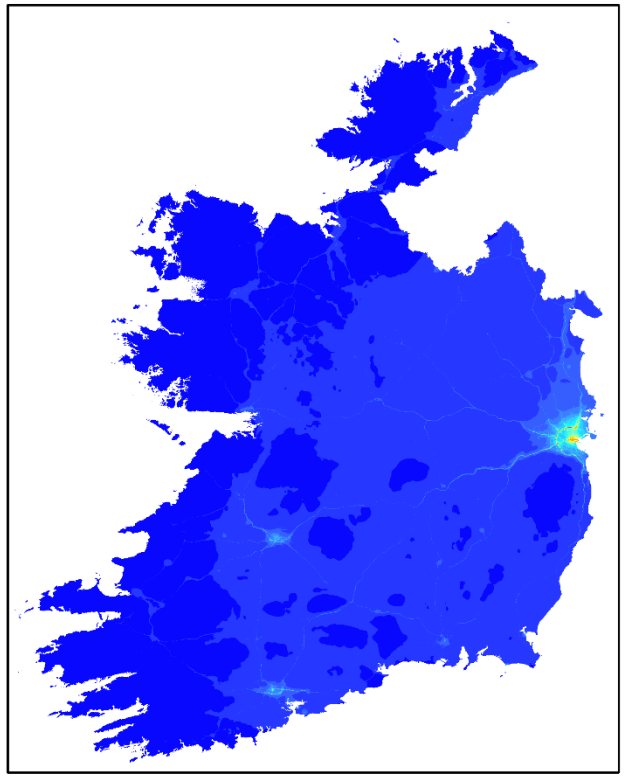
- < 2.5
- 2.5 - 5.0
- 5.0 - 7.5
- 7.5 - 10.0
- 10.0 - 12.5
- 12.5 - 15.0
- 15.0 - 17.5
- 17.5 - 20.0
- 20.0 - 22.0
- 22.0 - 24.0
- 24.0 - 26.0
- 26.0 - 28.0
- 28.0 - 30.0
- 30.0 - 32.0
- 32.0 - 34.0
- 34.0 - 36.0
- 36.0 - 38.0
- 38.0 - 40.0
- 40.0 - 50.0
- > 50.0

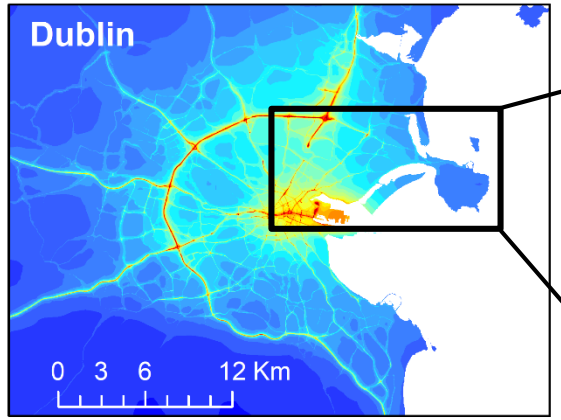
Annual average NO_2 pollution maps – Dublin zoom (2019)

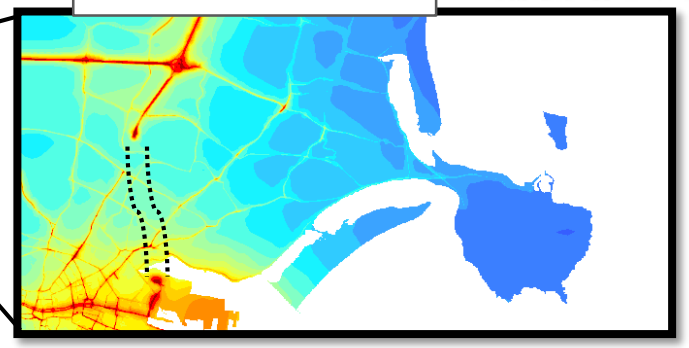
Pollution maps (2 of 3)

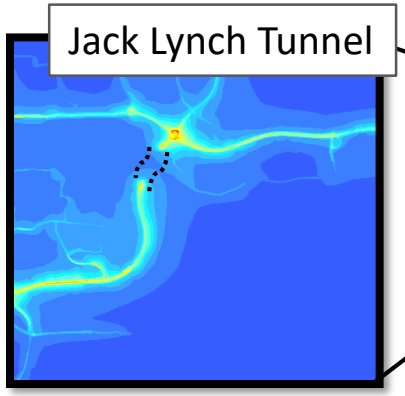


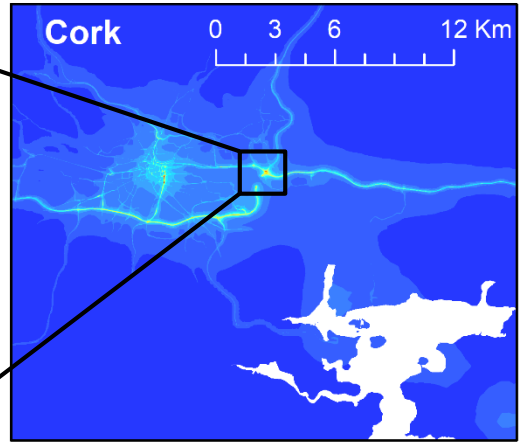


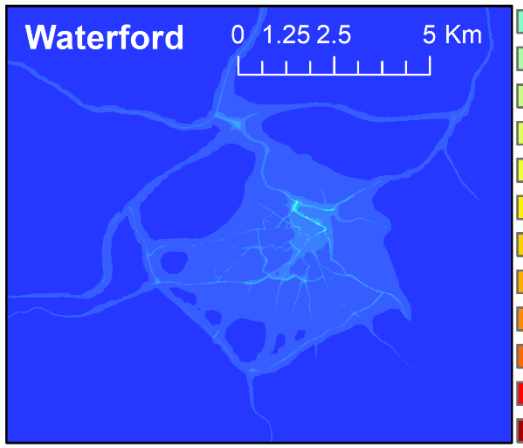


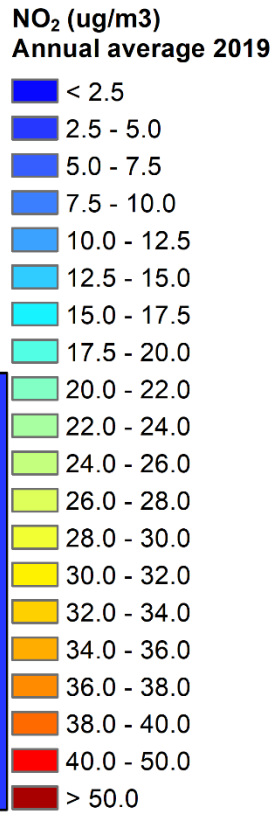








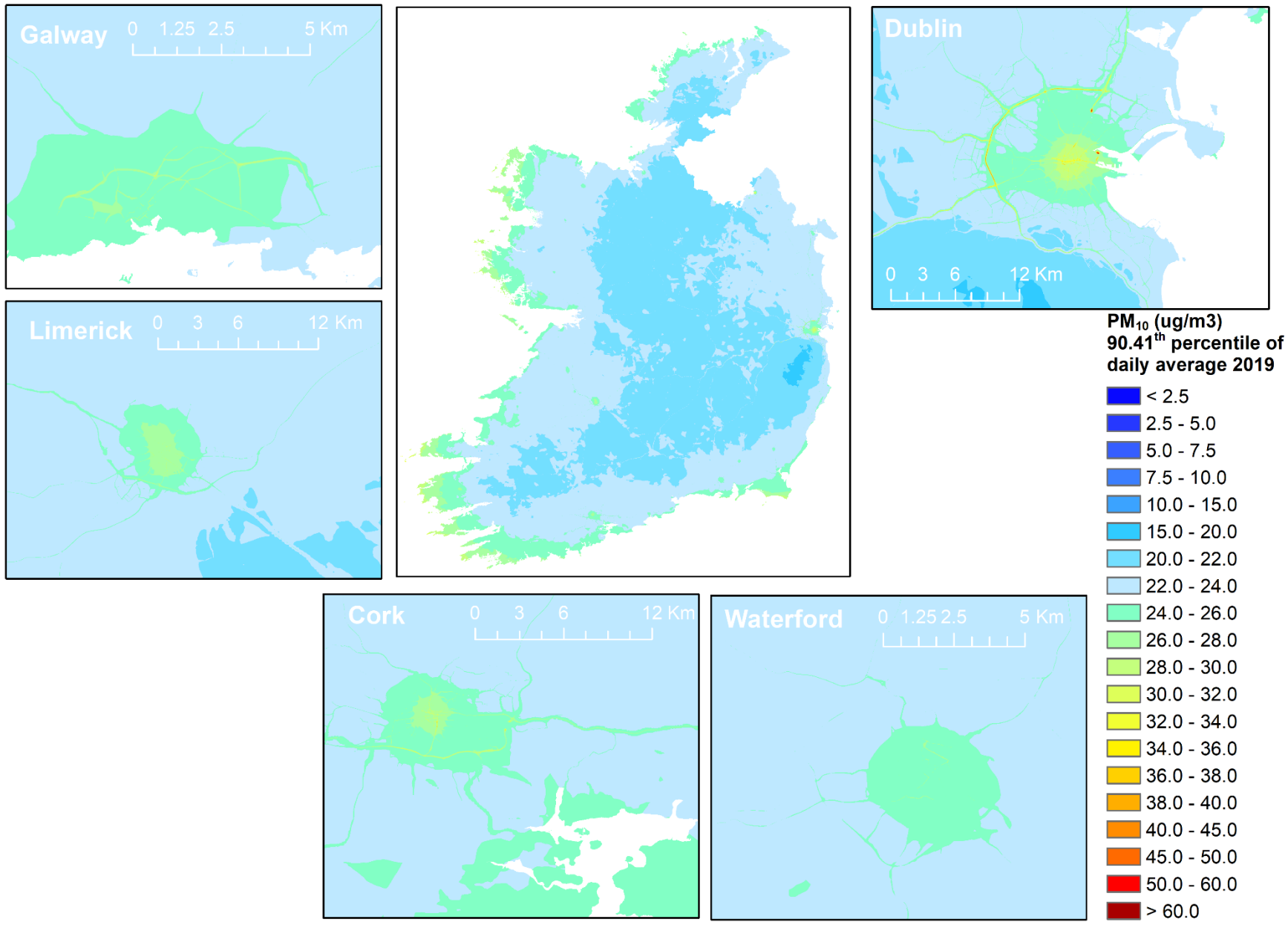




Coupled system annual average NO_2 pollution maps (2019)

- NO_2 exceedances dominated by road traffic
- Explicitly modelled tunnels (dashed black lines) clear from maps

Pollution maps (3 of 3)



Coupled system 90.41st percentile PM_{10} pollution maps (2019)

- Note influence of sea salt on coastal PM_{10}

Summary

Further information (Ireland)

- Interactive Air Quality in Ireland Report 2022 includes a summary of the modelling work:

  https://www.epa.ie/publications/monitoring--assessment/air/air-quality-in-ireland-2022.php

- Full CERC project report also available online

System summary

- Powerful system that links regional models to ADMS allowing regional-to-streetscale air quality modelling
- Runs in Linux environment (HPC, Virtual Machines)
- Model run times slightly longer than ADMS, using archived regional model data
- MAQS version 1.2 released November 2023

Application summary

- Croatia (DMHZ):
  - Regional modelling complete
  - Coupled system being configured for Zagreb
- Ireland (Irish EPA):
  - Modelling for 2018 & 2019
- Other:
  - Hong Kong (HKUST & EPD): Operational air quality forecasting system
  - Punjab, Pakistan (Sciences Po): Ongoing research project modelling counterfactual scenarios
  - Southampton region (University of Hertfordshire): Ongoing EMERGE research project focused on shipping
  - Regions of UK (Edinburgh, Birmingham and Lancaster universities): Applications as part of MAQS-Health project

Thank-you for listening

Jenny.Stocker@cerc.co.uk

Darijo.Brzoja@cirus.dhz.hr