THE DEVELOPMENT OF A BUILDING-RESOLVED AIR QUALITY FORECAST SYSTEM BY A MULTI-SCALE MODEL APPROACH AND ITS APPLICATION TO MODENA URBAN AREA, ITALY

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HARMO 20

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Goals of the study*

- Develop a hybrid forecast modelling system able to provide hourly NO_2 and NO_x concentration fields at a building-resolving scale in the urban area of Modena

- Produce a dynamic population-weighted exposure forecast at hourly time step from estimated NO_2 concentrations.

Why?

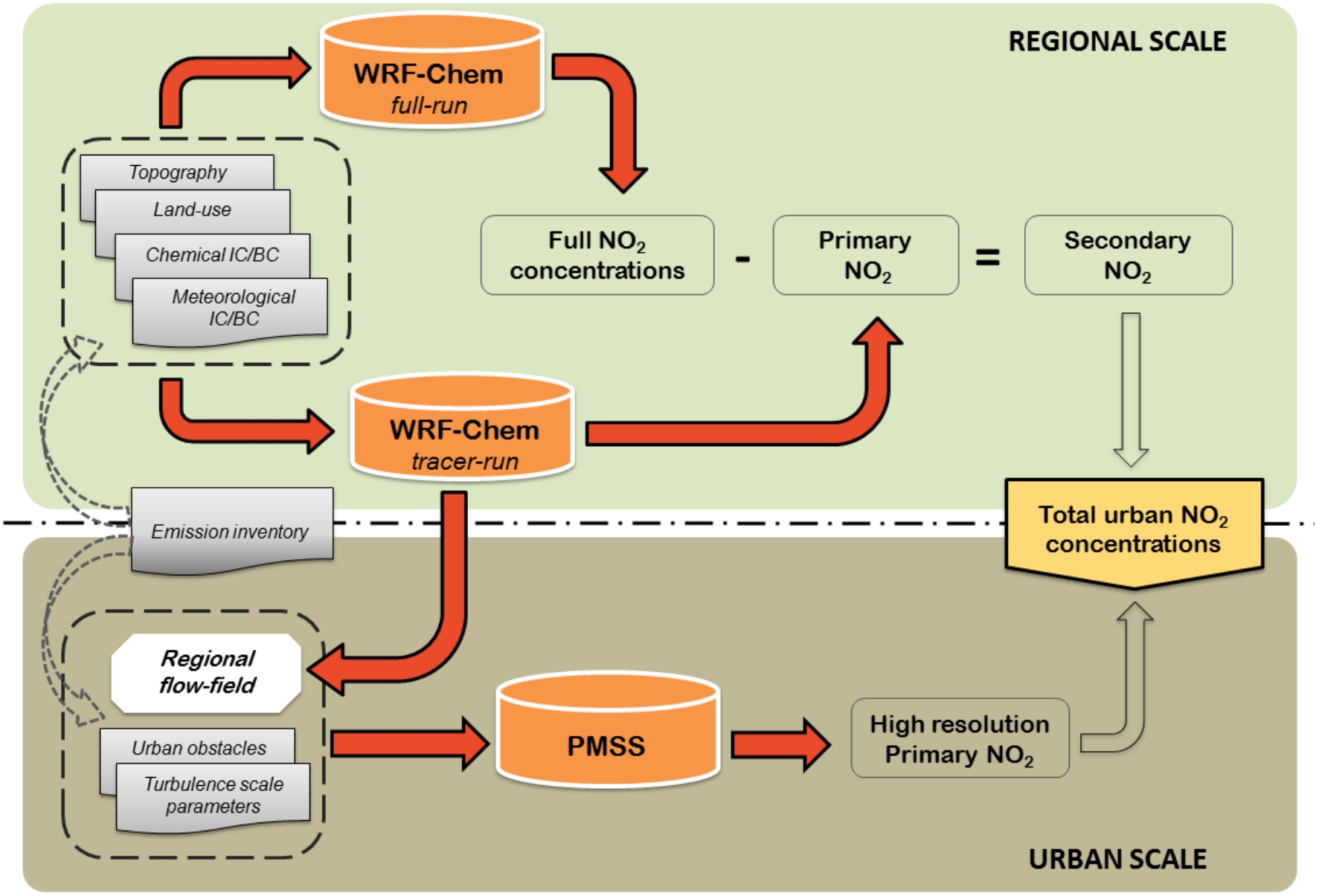
1) Identify a tool for local health and air managers to make informed decisions on mitigation measures to reduce public exposure risk.

2) Given a forecast of impending poor air quality, air quality managers may issue car-pooling advisories, authorize free public transportation or impose other mitigation and warning measures.

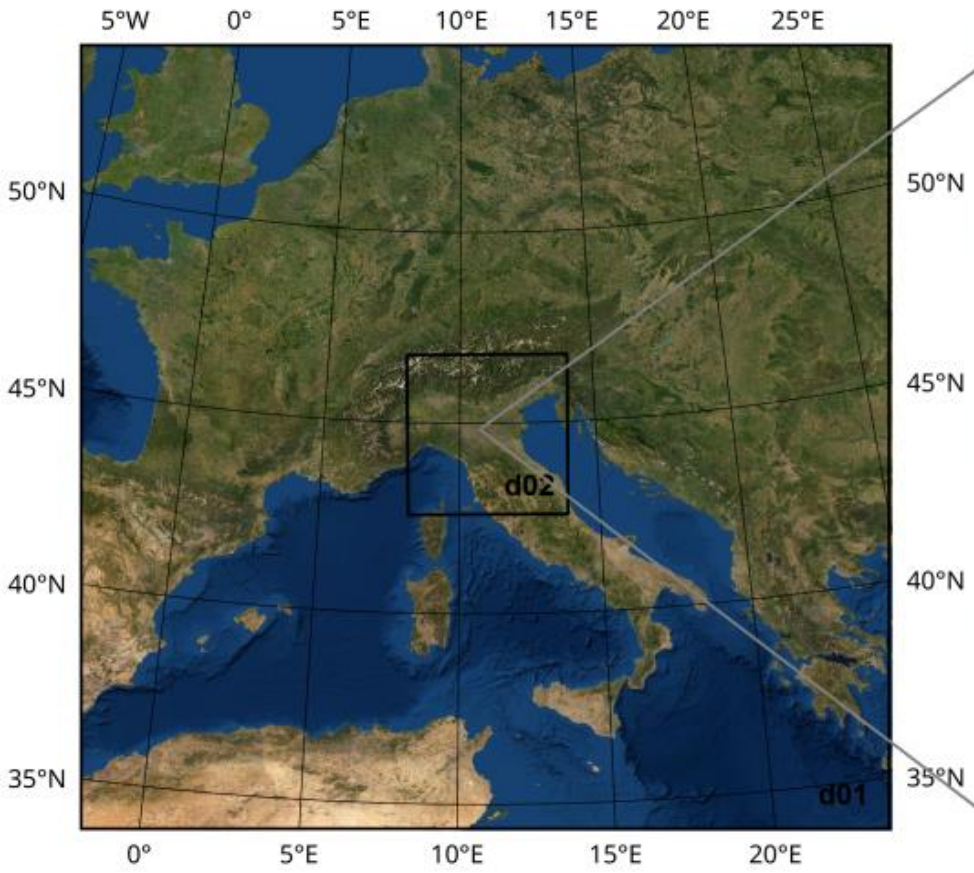
3) Help citizens take timely protective actions (e.g. wearing masks, staying indoors, change daily street route) and to help governments control emissions through dynamic management actions.

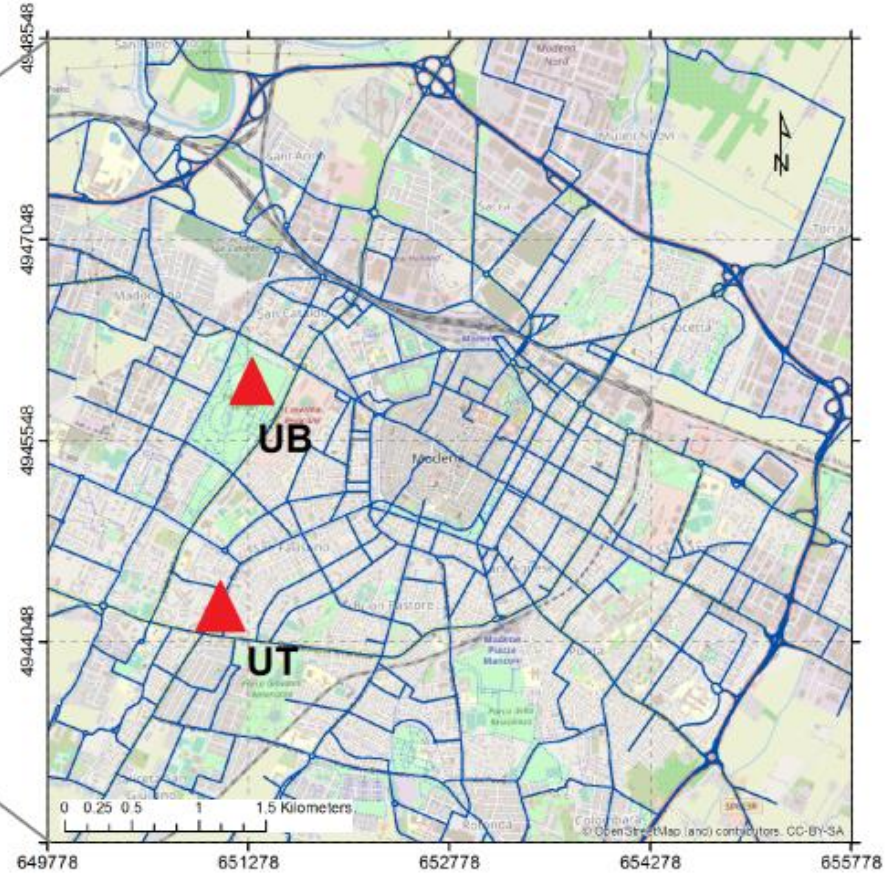
*Veratti et al. (2021): Urban population exposure forecast system to predict NO_2 impact by a building-resolving multi-scale model approach – under review @*Atmospheric Environment*

Flow-chart of the modelling system strategy



Case study





WRF-Chem

Two one-way nested domains:

d01 -> resolution **15 km**

d02 -> resolution **3 km**

Parallel Micro SWIFT SPRAY (PMSS)

Modena urban domain -> **6 km x 6 km**

Resolution -> **4 m**

Domain subdivided in **16 Tiles**

WRF-Chem set-up

Main parametrizations		Input parameters	
Land-surface model	**Noah LSM**	Land-use	**Corine 2012**
Boundary Layer scheme	**YSU**	Meteorological IC/BC	**GFS**
Gas-phase mechanism	**MOZART**	Chemical IC/BC	**WACCCM global model**
Aerosol model	**MOSAIC 4 bins**	Vertical grid	**35 levels (30m ÷ 50 hPa)**

Biogenic emissions: computed on-line with MEGAN v2

Anthropogenic emissions: TNO-MACC III emission inventory, modified over the province of Modena:

- SNAP 7 emis.: bottom-up approach (traffic fluxes + Cold & Hot EMEP/EEA EF*)
- SNAP 9 emis. taken from the local regional emission inventory (ARPAE)
- SNAP 2 emis.: downscaled according to building volumes and CNG consumption
- SNAP 3 emis.: downscaled to industrial areas

*Ntziachristos, L. & Samaras, Z. EMEP/EEA emission inventory guidebook 2019

PMSS emissions estimation

WRF-Chem and PMSS are fed by the same set of emissions
to keep consistency between concentration maps produced at regional and urban scales

Traffic emissions:

Bottom-up approach

Traffic flows data on the main urban road were estimated by PTV VISUM

EMEP/EEA Cold & Hot Emissions Factors

Tailored temporal modulations based on traffic measurements at 230 crossroads

Non-industrial combustion emissions (domestic heating): TNO MACC emissions were distribute to each building of the city using the building volume as a proxy variable. The more volume a building has, the more emissions were associated at that building

Industrial combustion emissions: TNO MACC emissions were distributed over the industrial area of the city

Waste management: Emissions were assigned to the incinerator plant of the city

Parallel Micro SWIFT SPRAY set-up

Micro-SWIFT		**Micro-SPRAY**	
Horizontal resolution	**4 m**	Horizontal resolution	**4 m**
Horizontal grid	**1504 x 1504 points**	Horizontal grid	**1504 x 1504 points**
Vertical grid	**from 3 up to 200m**	Vertical grid	**from 3 up to 200m**
	20 vertical levels		**10 vertical levels**
Interpolation method	**Cressman 2D**	Emission time step	**5 s**
Fast momentum solver	**activated**	Averaging period for concentrations	**3600 s**

Forecasted period: February 1 - 28 2019

Run Strategy: The model run covers two days with the first of the two used as spin-up and then discarded. The run spans from day 0 to day+1.

MODELS EVALUATION

The models evaluation regarded three different aspects:

- Operational performances

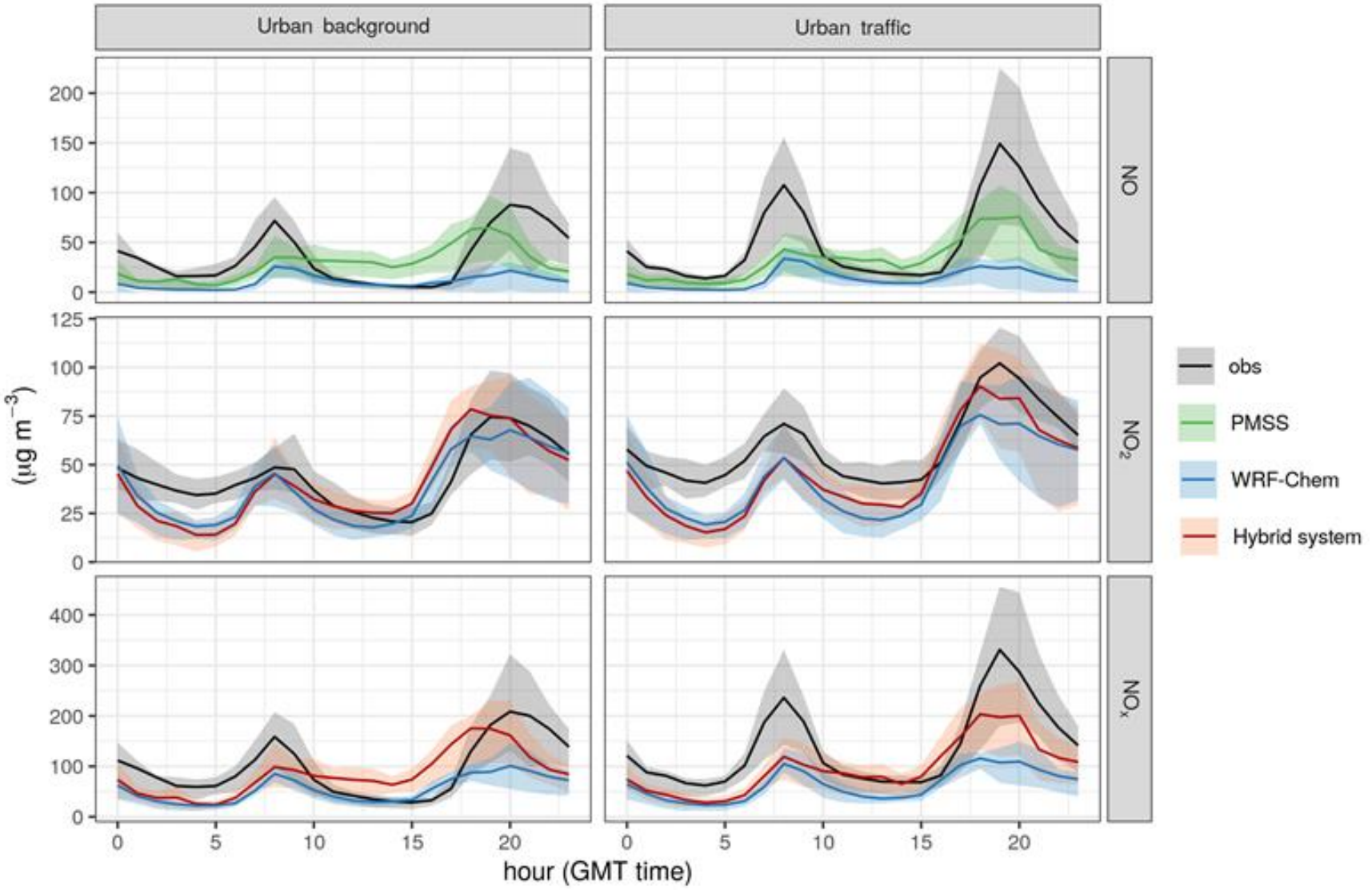
- Fulfilment of the standard assessment MQO (Model Quality Objective) for NO_2 as defined by Fairmode guide lines.

- Fulfilment of the additional MQO forecast

In order to highlight the strengths and weaknesses of the Hybrid approach the performances of he hybrid modelling system are compared with the performances of WRF-Chem "stand-alone"

MODELS EVALUATION: Operational performances

Mean daily cycle: Solid lines represent the daily mean cycle, meanwhile shaded area show the variability between 25th and 75th percentiles.



MODELS EVALUATION: Operational performances

Statistical metrics:

Station	Pollutant	NME	R	FAC2	FB	NAD	NMSE
Reference acceptance criteria for urb. Env.*				> 0.30	< 0.67	< 0.50	< 6
Urban Background	NO_2	-0.09 (-0.13)	0.60 (0.58)	0.69 (0.68)	0.09 (0.14)	0.22 (0.23)	0.32 (0.34)
	NO_x	-0.14 (-0.44)	0.41 (0.63)	0.53 (0.59)	0.15 (0.57)	0.33 (0.34)	0.89 (1.25)
Urban Traffic	NO_2	-0.24 (-0.36)	0.70 (0.64)	0.71 (0.60)	0.27 (0.44)	0.20 (0.25)	0.26 (0.42)
	NO_x	-0.30 (-0.61)	0.58 (0.62)	0.59 (0.39)	0.35 (0.87)	0.30 (0.44)	0.80 (2.17)

Legend:

Numb. → Hybrid system

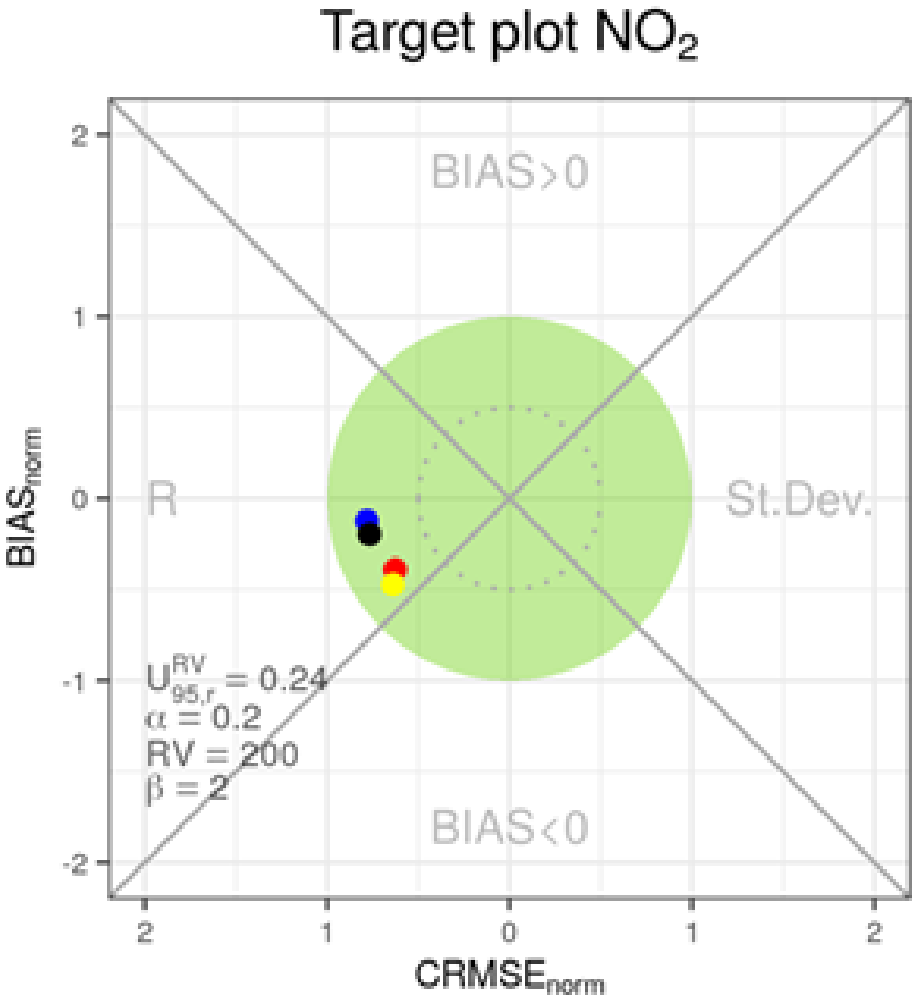
(numb.) → WRF-Chem "stand-alone"

→ Hybrid system performs better than WRF-Chem "stand-alone"

→ WRF-Chem performs better than the Hybrid system

*Hanna, S.R., Chang, J.C., 2012. Acceptance criteria for urban dispersion model evaluation. Meteorological Atmospheric Physics 116, 133–146

MODELS EVALUATION: Fulfilment of the standard assessment MQO



MQO is fulfilled when MQI ≤ 1

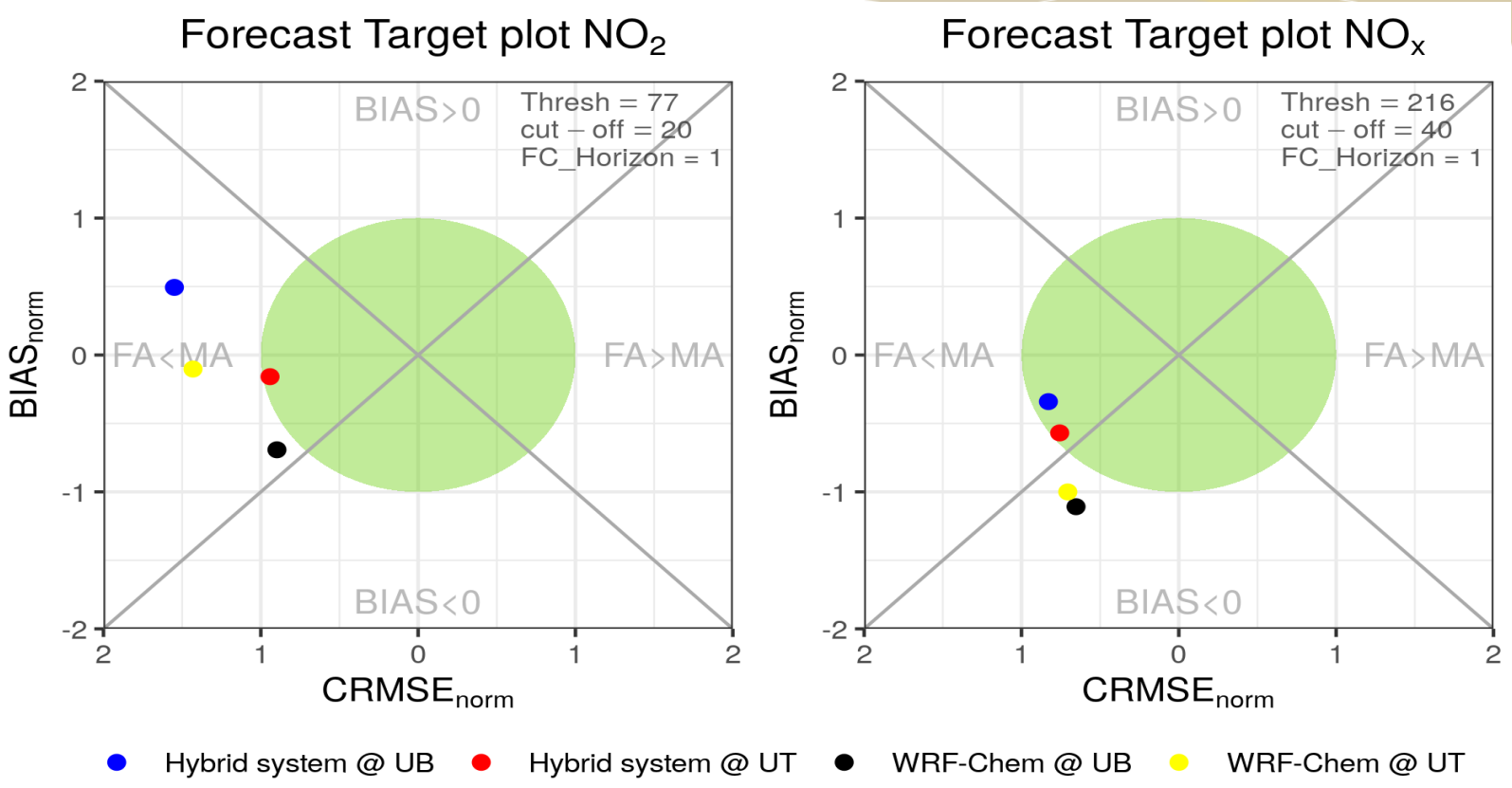
$$MQI = \frac{RMSE}{\beta RMS_U}$$

RMSE ≤ βRMS_U

- Hybrid system @ UB
- Hybrid system @ UT
- WRF-Chem @ UB
- WRF-Chem @ UT

Station	Model	MQI
Urban background	Hybrid System	0.79
	WRF-Chem	0.79
Urban traffic	Hybrid System	0.74
	WRF-Chem	0.79

MODELS EVALUATION: Fulfilment of the MQO forecast



Station	Model	Pollutant	$MQI_{forecast}$
Urban background	Hybrid system	NO_2	1.70
	WRF-Chem	NO_2	1.51
Urban traffic	Hybrid system	NO_2	0.98
	WRF-Chem	NO_2	1.15

Station	Model	Pollutant	$MQI_{forecast}$
Urban background	Hybrid system	NO_x	0.93
	WRF-Chem	NO_x	1.24
Urban traffic	Hybrid system	NO_x	0.96
	WRF-Chem	NO_x	1.29

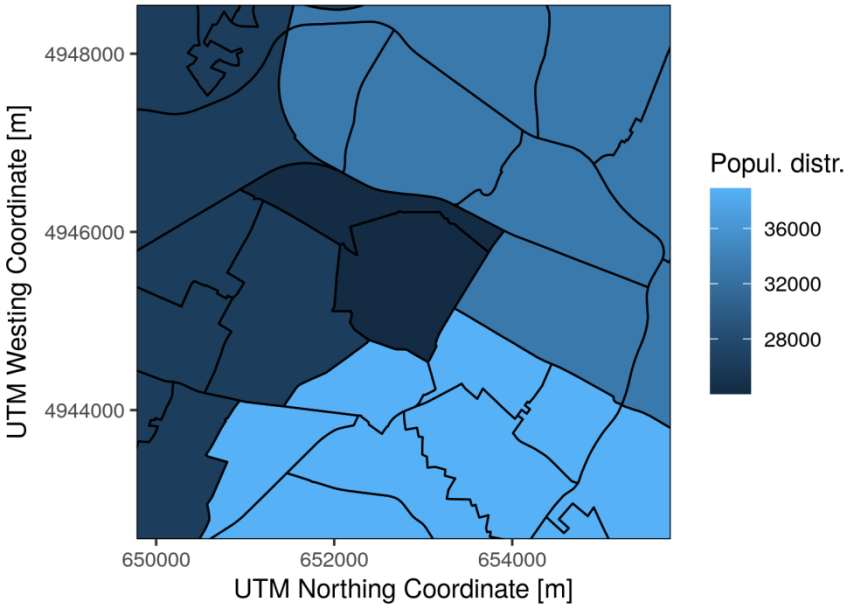
Hourly Exposure assessment from predicted NO_2 conc.

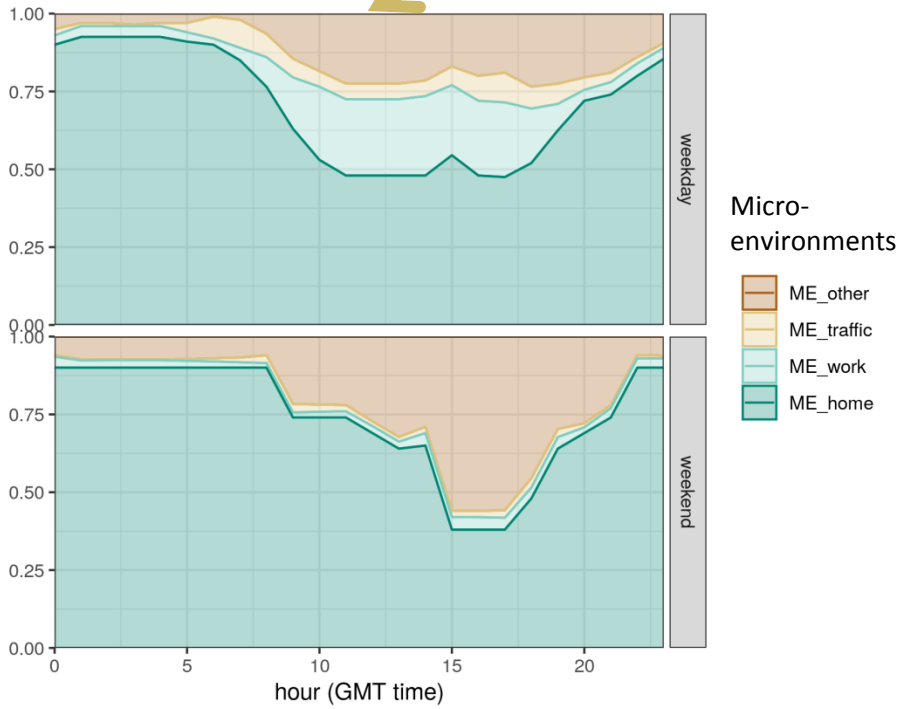
Hourly NO_2 exposure is computed considering the diurnal population dynamics:

Population data from 4 city large neighbourhoods

Definition of 4 micro-environments in the city: Home, Work, traffic and other

Time profile for diurnal population activities*





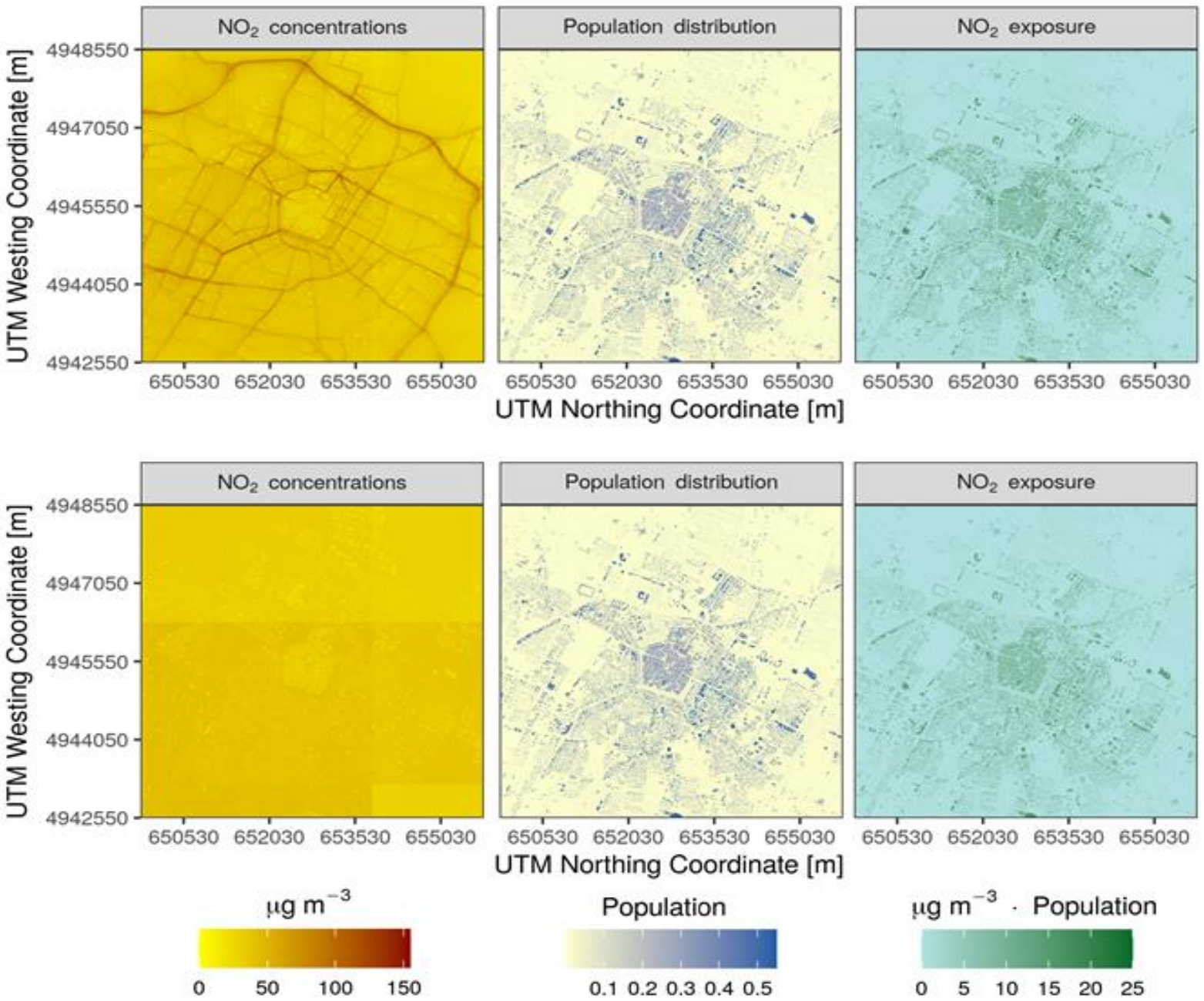
*Ramacher et al. (2019): Urban population exposure to NOx emissions from local shipping in three Baltic Sea harbour cities – a generic approach

Background hypothesis: The role of commuters was neglected during the distribution of the population in each urban micro-environment.

NO_2 "long-term" exposure assessment

Hybrid System

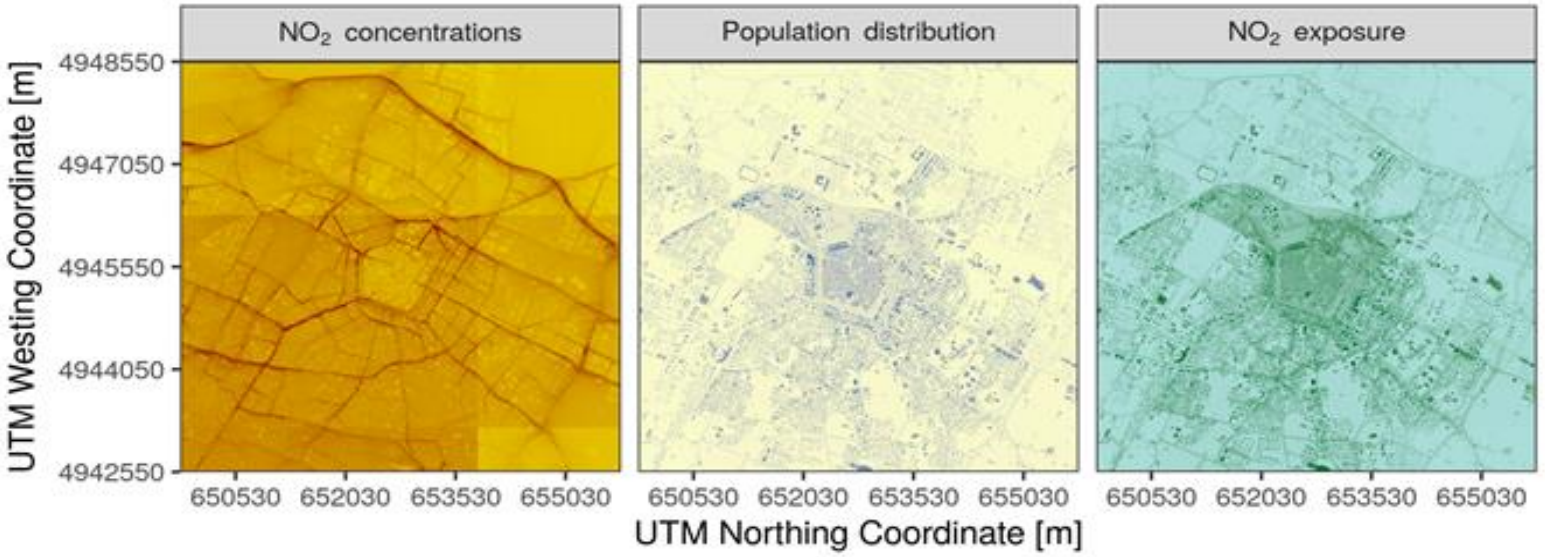
WRF-Chem «stand-alone»



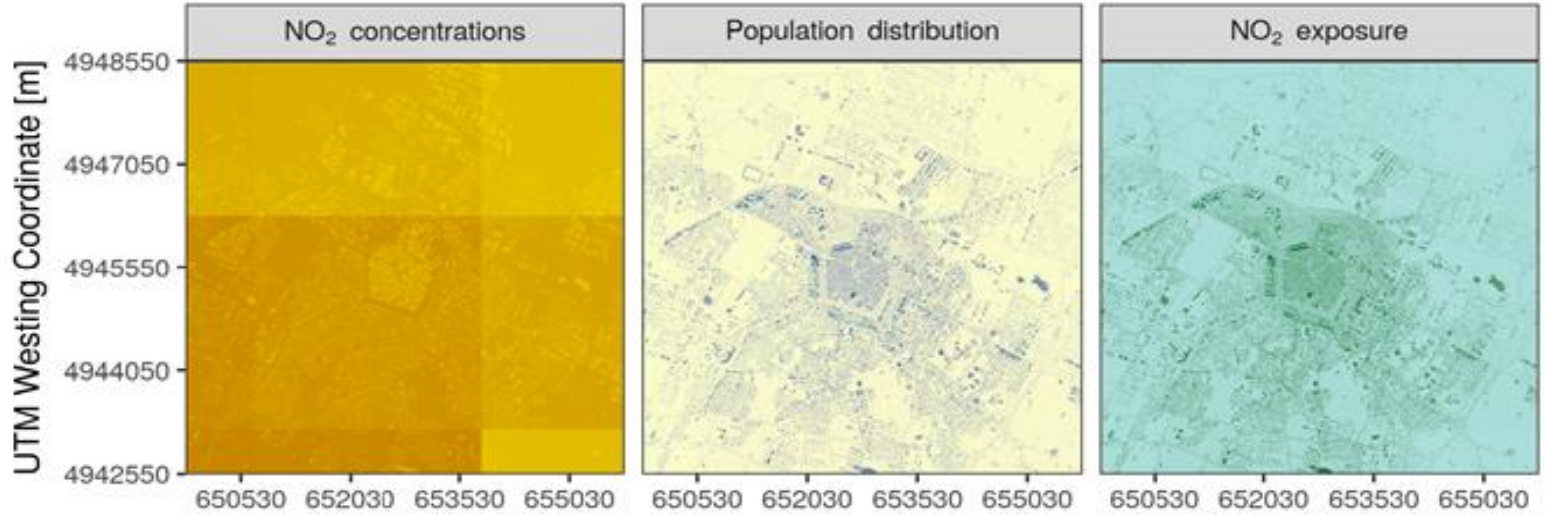
NO_2 "short-term" exposure assessment

(only rush hours are considered)

Hybrid System



WRF-Chem «stand-alone»



Conclusions 1/2

- Two complex models have been integrated to create an air quality forecast system able to predict NO_2 and NO_x concentrations with a time horizon of 1 day, in a urban environment at very high resolution (4m).

- The performance of the modelling system has been evaluated at two urban stations (traffic and background sites). Operational performances of the modelling system showed satisfactory results in urban environment, with statistical score that fulfil the acceptance criteria for dispersion modelling in urban environment.

- The analysis of the operational performances highlighted also the ability of the hybrid system in reproducing the transport phenomena for the primary pollutants contribution. The statistical scores of the full WRF-Chem run indicate that modelled NO_2 concentrations by WRF-Chem at urban background site (where primary NO_2 concentrations are low) express very similar performance to the hybrid system. Otherwise, at traffic site where NO and primary NO_2 are not negligible, the hybrid system expresses clearly better performance with respect to full WRF-Chem run.

- NO_2 Model Quality Objective is met for both the hybrid modelling system and also for the WRF-Chem stand alone at both the urban stations, confirming the ability of WRF-Chem in reproducing the formation of secondary NO_2.

Conclusions 2/2

- On the other hand, the hybrid modelling system met the MQO forecast for NO_x at both the urban stations and only at urban traffic station for NO_2.

- The population exposure to forecasted NO_2 concentrations has been evaluated adopting a generic model of dynamic population activity.
  The hybrid system was shown to be particularly suited for assessing short-term peak exposure in areas influenced by traffic emissions. On the other hand, due to the limited time spent by the population within traffic related environments, the long-term population exposure calculated by the hybrid system tends to be similar to the WRF-Chem stand-alone estimate.