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CARBOTRAF: A DECISION SUPPORT SYSTEM FOR REDUCING POLLUTANT EMISSIONS BY ADAPTIVE TRAFFIC MANAGEMENT

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Abstract: Traffic congestion with frequent "stop & go" situations causes substantial pollutant emissions. Black carbon (BC) is a good indicator of combustion-related air pollution and results in negative health effects. Both BC and CO_2 emissions are also known to contribute significantly to global warming. Current traffic control systems are designed to improve traffic flow and reduce congestion. The CARBOTRAF system combines real-time monitoring of traffic and air pollution with simulation models for emission and local air quality prediction in order to deliver on-line recommendations for alternative adaptive traffic management. The aim of introducing a CARBOTRAF system is to reduce BC and CO_2 emissions and improve air quality by optimizing the traffic flows. The system is implemented and evaluated in two pilot cities, Graz and Glasgow.
Model simulations link traffic states to emission and air quality levels. A chain of models combines micro-scale traffic simulations, traffic volumes, emission models and air quality simulations. This process is completed for several ITS scenarios and a range of traffic boundary conditions. The real-time DSS system uses all these model simulations to select optimal traffic and air quality scenarios. Traffic and BC concentrations are simultaneously monitored. In this paper the effects of ITS measures on air quality are analysed with a focus on BC.

Key words: *Black carbon - traffic management – pollutant dispersion modelling - ITS - emission reduction*

1. INTRODUCTION TO CARBOTRAF

The aim of the CARBOTRAF project is the development of a decision support system (DSS) for adaptively influencing traffic in real-time to reduce black carbon (BC) and carbon dioxide (CO_2) emissions caused by road transport in urban and inter-urban areas. Black carbon is chosen as indicator for traffic related air quality. It proves strongly related to health effects caused by exposure to traffic emissions.

An overview of the concept is given in Figure 1. One part of the system is the online database. Traffic sensors, smart cameras and black carbon monitors are installed at selected points in the pilot cities and deliver the real-time traffic and pollutant concentration data. Meteorological data are gathered as well. The offline database of the system includes traffic, emission, and BC concentration data for a catalogue of intelligent traffic system measures (ITS). The online decision support system uses the online information to choose the optimal ITS scenario for the real-time condition with respect to both traffic flow and air quality based on all results in the look-up-table ITS catalogue.

The data in these look-up-table database of traffic and emission scenarios are the results of detailed simulations for traffic, emissions and air quality. Separate models for each topic are therefore coupled in a model chain, including the following modules:

- Micro-scale traffic models: S-Paramics (Glasgow) and VISSIM (Graz)
- Emission model: AIRE + COPERT IV

- Atmospheric dispersion model: IFDM + OSPM

The micro-scale traffic models start from the network information, known traffic flows, signal plans, vehicle fleet composition and vehicle dynamics. For each ITS action simulations are completed for a range of boundary conditions (variations in traffic conditions outside the simulated network). The micro-scale simulations yield the vehicle speeds and trajectories.
The output of the traffic models is used as input for the emission calculation together with detailed information on the vehicle emission categories. The emission model yields the pollutant emission for every link for the entire network.
The pollutant dispersion model starts from the emissions and meteorological data to simulate the pollutant concentrations. Available information on building dimensions along the network is used to simulate street canyon effects on the dispersion process.
The focus of this paper is the impact of the ITS measures on the air quality.

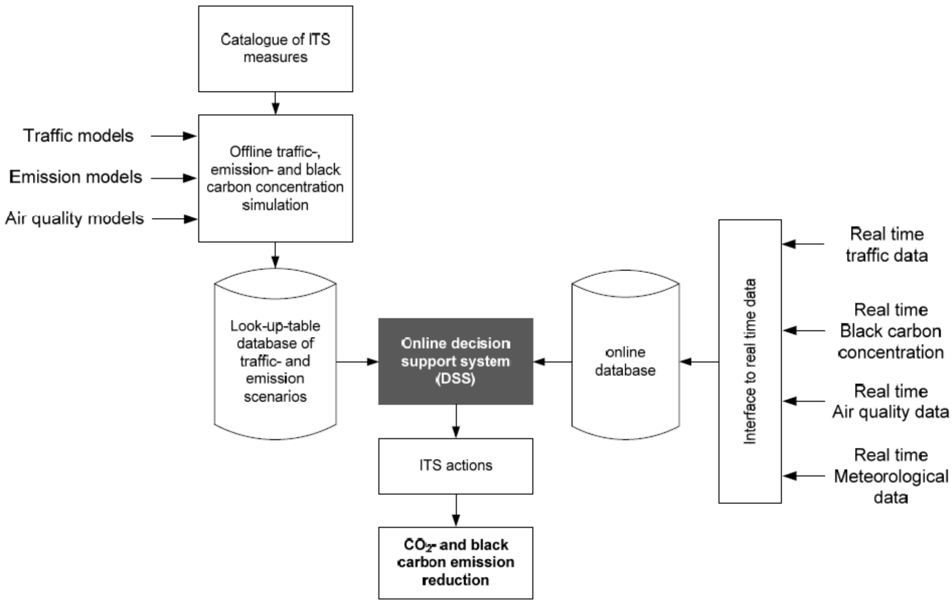

Figure 1. The CARBOTRAF system

2. METHODOLOGY DISPERSION MODELLING

The IFDM model (Immision Frequency Distribution Model), a bi-gaussian plume model, has been selected for use in CARBOTRAF. A street canyon module based on the OSPM model (Berkowicz et al. 1997) is applied to simulate the dispersion in street canyons. In a series of studies the IFDM model has been validated for use in urban applications (Lefebvre et al. 2013a, Lefebvre et al 2013b, Lefebvre et al. 2011). Within this project, an extra validation against available historical NO_2 data for Glasgow has been performed, proving the model skill.
For both test sites, simulations are performed for each ITS scenario and boundary condition for 252 meteo conditions, a combination of 36 possible wind directions at 10° interval and 7 different stability classes.

3. TEST SITES

The test site in Graz, presented in Figure 2, comprises two main arterial roads linking the Mur valley in the north of the city with the inner city centre. ITS (Intelligent Traffic Systems) actions that are implemented are a VMS (Variable Message Sign) and traffic light optimization. Five additional traffic sensors are installed on the test site (Figure 2: B, D, E, F, G). Two BC monitors are installed at each of the arterial roads (AQ6, AQ7) and one additional monitor at the AQ monitoring station in the center of the test site (Graz North).
The second test site is located in the West end of Glasgow (Byres Road area). Local stakeholders expressed their preference to this area because it has congestion and pollution problems for many years. ITS actions that are implemented are again VMS and traffic light optimization. VMS is used to reroute

drivers away from congested area where BC and CO_2 emissions are expected to be high and air quality can be improved by decreasing the amount of traffic and decrease the stop-and go. Five traffic sensors and two BC monitors are installed near the main roads in the test site.

Figure 2. Overview of the test site in Graz (left) and in Glasgow (right), validated networks highlighted.

4. EMISSIONS

The following tables give an overview of the total BC emissions over the network. For both test sites, the impact of the different ITS scenarios (traffic light programs and variable messaging systems) is maximal a decrease in total emissions with 5% and worst-case an increase with 2%. The change in emission at locations along the network can however be much larger.

Table 1. Total BC emissions for all ITS scenarios as percentage of the total mission of the base scenario of the respective boundary condition – Glasgow. TS1-2-3 are different traffic light programs, VMS10-20-30 are the VMS scenarios with respective compliance rates, the final three scenarios are combinations of both. BC1-5 are 5 different boundary condition and the average over all boundary conditions.

	Base	TS1	TS2	VMS10	VMS20	VMS30	TS3	TS3-VMS10	TS3-VMS20	TS3-VMS30
BC1	100%	101%	95%	100%	99%	99%	99%	98%	97%	97%
BC2	100%	100%	97%	102%	100%	101%	99%	101%	100%	99%
BC3	100%	101%	99%	100%	100%	100%	100%	97%	99%	98%
BC4	100%	102%	99%	101%	101%	102%	101%	100%	99%	101%
BC5	100%	99%	99%	100%	101%	101%	101%	99%	100%	99%
average	100%	101%	98%	101%	100%	101%	100%	99%	99%	99%

5. AIR QUALITY RESULTS

The results of the dispersion modelling yield the pollutant concentration for each meteo condition, traffic boundary condition and ITS scenario. For Graz and Glasgow we have in total respectively 9828 and 12600 sets of results. Each set of results lists the pollutant concentration at each receptor point of the grid used for the simulation. This set of results can be interpolated to a pollutant concentration map. A single meteo condition map has large gradients in concentration as the effect of emissions is observed downwind of the source. To present more informative maps, the pollutant concentrations have been averaged over the 252 meteo conditions prior to interpolation, leading to maps which clearly show the regions where the larger pollutant concentrations are expected. Important to stress here, is the absence of any background contribution to the simulated pollutant concentrations (not feasible for scenario calculations).

To highlight the locations where the impact of ITS measures is observed, ITS scenarios are compared with the base scenario in concentration difference maps, again averaged over all meteo conditions. An example of a BC concentration difference map is given in Figure 3. This map shows for Graz the impact of rerouting the traffic from the western arterial road to the eastern arterial for one specific traffic light program and compliance rate. This traffic measure causes decreases of up to 0.3 µg/m³ along the western road and increases of up to 0.1 µg/m³ along the eastern road. The exact influence of an ITS scenario on

the pollutant concentration depends on the location, the meteo condition and the combined effect of the ITS measure, including the traffic light program, and the compliance rate.
The concentration maps give a clear overview of the spatial spread of the ITS effects averaged over all meteo conditions. In the next figures, an overview is given of the ITS impact for individual meteo conditions for a single location in each pilot area. Box plots show the range effects that can be expected.

Table 2. Total BC emissions for all ITS scenarios as percentage of the total mission of the base scenario of the respective boundary condition – Graz. The different boundary conditions BC1-3 reflect different traffic volumes at different time slots.

Traffic light Program	VMS	Compliance	BC1 (6-7)	BC2 (6:30-7:30)	BC3 (7-8)
W2E2	do nothing	/	100%	100%	100%
W2E2	Go East	5	99%	101%	99%
W2E2	Go East	10	99%	98%	97%
W2E2	Go East	15	98%	98%	96%
W2E2	Go West	5	99%	100%	99%
W2E2	Go West	10	99%	100%	101%
W2E2	Go West	15	99%	101%	101%
W2E5	Go West	5	99%	99%	96%
W2E5	Go West	10	100%	99%	97%
W2E5	Go West	15	99%	100%	98%
W5E2	Go East	5	100%	100%	99%
W5E2	Go East	10	100%	99%	98%
W5E2	Go East	15	100%	98%	97%

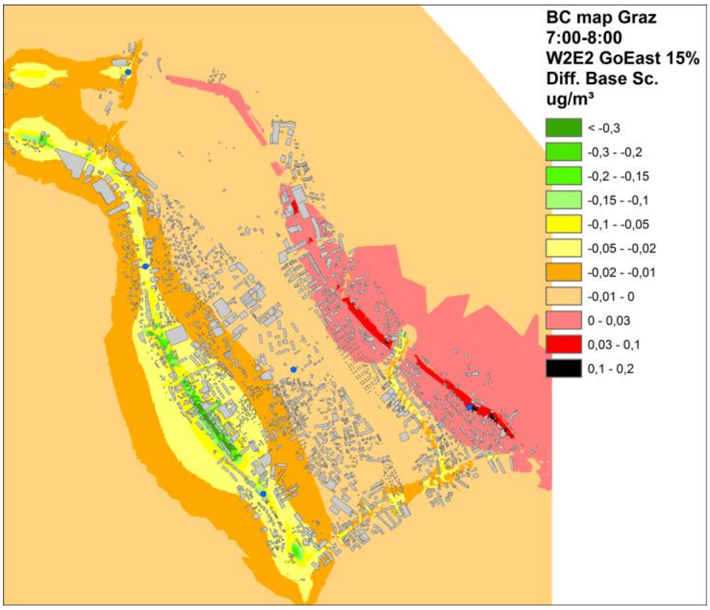

Figure 3: Example of a black carbon concentration difference map for Graz. Results of the ITS scenario and the base scenario have been averaged over all meteo conditions. Buildings in grey, units: µg/m³.

6. CONCLUSIONS

The CARBOTRAF DSS potential impact on air quality in both pilot cities is analysed using the simulation results. Implementation of ITS measures leads to possible changes in total BC emissions over the full network with -5% to +2%. The effect on the BC concentration is illustrated for target locations. Averaged over all wind directions and stability classes the ITS measures lead to changes in the range of -0.3 to +0.1 µg/m³ BC. Maximal influence on the BC concentrations for individual meteo conditions range from -0.2 µg/m³ to almost -2.0 µg/m³. The effects of ITS measures have large spatial and temporal variations. Overall, the best performing ITS measures have the potency to significantly improve the air quality at crucial locations. Averaged over the full test site effects remain fairly limited.

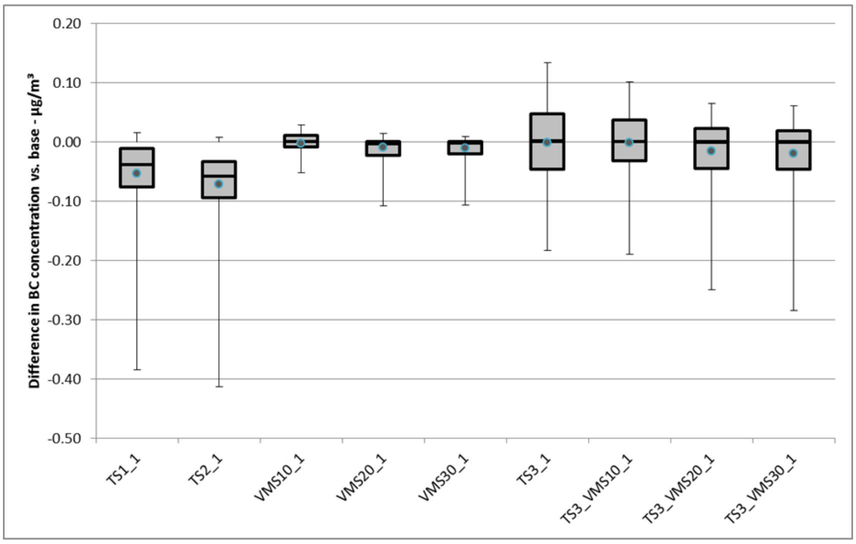

Figure 4. Boxplot of the BC difference respective to the base scenario. Location Byres Rd./ Uni. Ave, Glasgow. Boundary Condition 1, units: µg/m³.

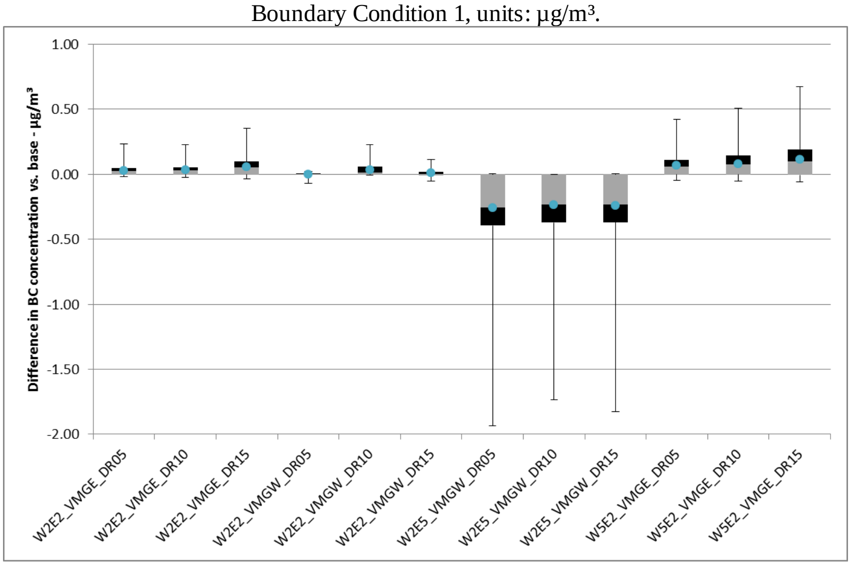

Figure 5. Boxplot of the difference in BC concentration *vs*. the base scenario, per ITS scenario, for BC monitor location 1, western arterial, Graz. Boundary condition 7:00 – 8:00, units µg/m³.

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