Air Quality Impact of a Decision Support System for Reducing Pollutant Emissions: CARBOTRAF

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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 CO2 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 CO2 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 these off-line 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.

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 (CO2) emissions caused by road transport in urban and inter-urban areas. Black carbon is chosen as an indicator for traffic related air quality, which is strongly related to health effects (UNEP 2011).

An overview of the concept is given in Figure 1. Data from microscopic traffic, emission and air quality simulation models is stored in an offline database. This database records the impact Intelligent transport system (ITS) measures have on the environment given information on prevailing traffic and meteorological conditions. Prevailing traffic states and meteorological conditions are used to model emissions and BC concentrations for each measure in the ITS catalogue. As a consequence, the offline database provides evidence on how to rank certain ITS measures given traffic state information. Real-time data is collected from traffic sensors, smart cameras, black carbon monitors, and meteorological stations in both pilot cities, yielding traffic flow rates and densities, pollutant concentrations, wind speed and direction respectively. The real-time data is processed by an online decision support system (DSS) that analyses which ITS measures are likely going to meet the objectives of reducing congestion as well as improving air quality. In order to accomplish this, the DSS incorporates statistical models of the offline data. These models are scored in real-time and a ranking of the ITS measures is computed and presented to the traffic operator.

As mentioned above, the offline data of traffic and emission scenarios are the results of detailed simulations for traffic, emissions and air quality. The respective simulation models are coupled in a modelling chain and include the following modules:

- Microscopic traffic models: S-Paramics (Glasgow) and VISSIM (Graz) (PTV 2012)
- Emission model: AIRE + COPERT IV
- Atmospheric dispersion model: IFDM + OSPM

The microscopic traffic models start from the network information, traffic flows, signal plans, local vehicle fleet composition and vehicle dynamics. For each ITS action, simulations are completed for a range of boundary conditions (variations of traffic conditions on the network). These simulations yield detailed vehicle trajectories including acceleration and speed for the study period (morning peak).

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 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.

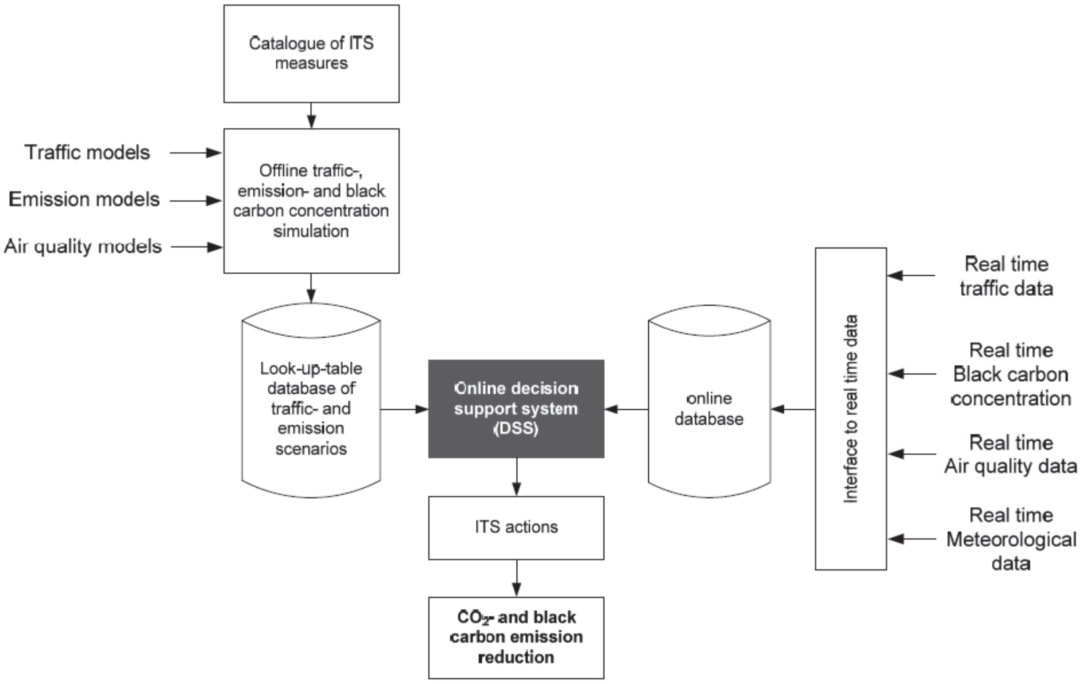

Figure 1: The CARBOTRAF System

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). Within this project, an extra validation against available historical NO_2 data for Glasgow is performed, proving the model skill. For both pilot cities, simulations are performed for each ITS scenario and boundary condition for 252 meteo conditions, a combination of 36 wind directions and 7 different stability classes.

3. Pilot Cities

The chosen 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 actions that are implemented are a VMS (Variable Message Sign) and traffic signal control. Five additional traffic sensors are installed on the test site. Two BC monitors are installed at each of the arterial roads and one additional monitor at the AQ monitoring station in the centre of the test site (Graz North).

The second site is the West end of Glasgow (Byres Road area). Stakeholders expressed their preference to this area as it has congestion and pollution problems for many years. ITS actions that are implemented are VMS and traffic signal control. 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 rerouting and decreasing the stop-and go cycles of the traffic. Four traffic sensors and two BC monitors are installed near the main roads in the test site.

Figure 2: Test sites 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 signal control and alternative route recommendations) results in a decrease in total emissions up to 5% and can result in some occasions in a slight increase of max 2%. However, the change in emission at corridor and junctions can 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 signal plans, 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 conditions 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 9828 and 12600 sets of results respectively. 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 concentrations 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 with equal weight, prior to interpolation. This yields maps which clearly show the regions where the higher pollutant concentrations are expected. Important to stress here, is that the pollutant maps only show concentrations resulting from local emissions and do not take into account background concentrations (not feasible for scenario calculations due to the absence of data).

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	No display	/	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%

To highlight the local impact of ITS measures, 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.

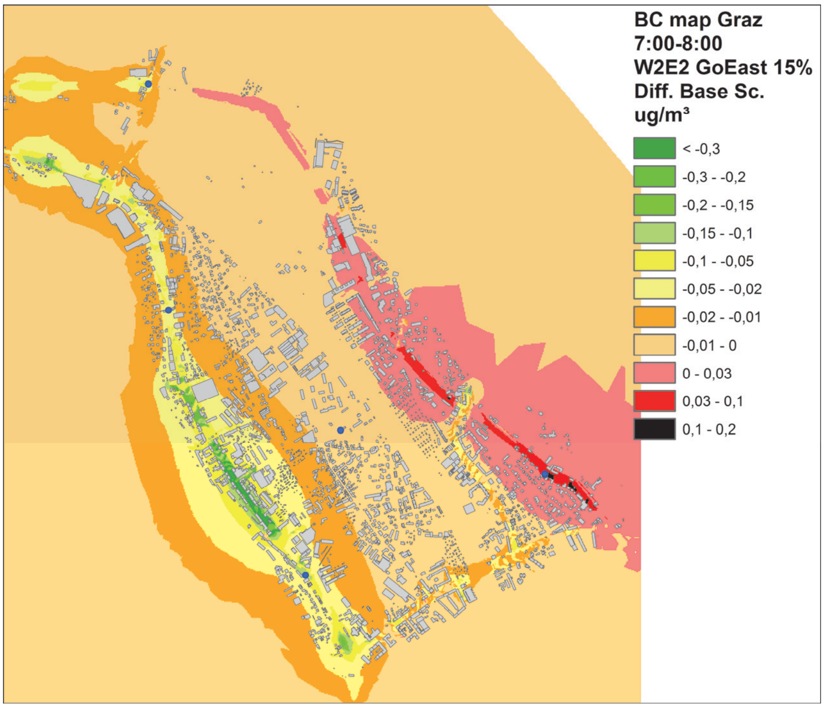

Figure 3: Example of a black carbon concentration difference map for Graz. Results of the ITS scenario and the base scenario have been averaged over all meteo conditions. Buildings in grey, units: μg/m³.

The concentration maps give a clear overview of the spatial spread of the ITS effects averaged over all meteo conditions. In Figures 4 and 5, an overview is given of ITS impact for individual meteo conditions for a single location in each pilot area. Box plots show statistics of simulated effects that can be expected.

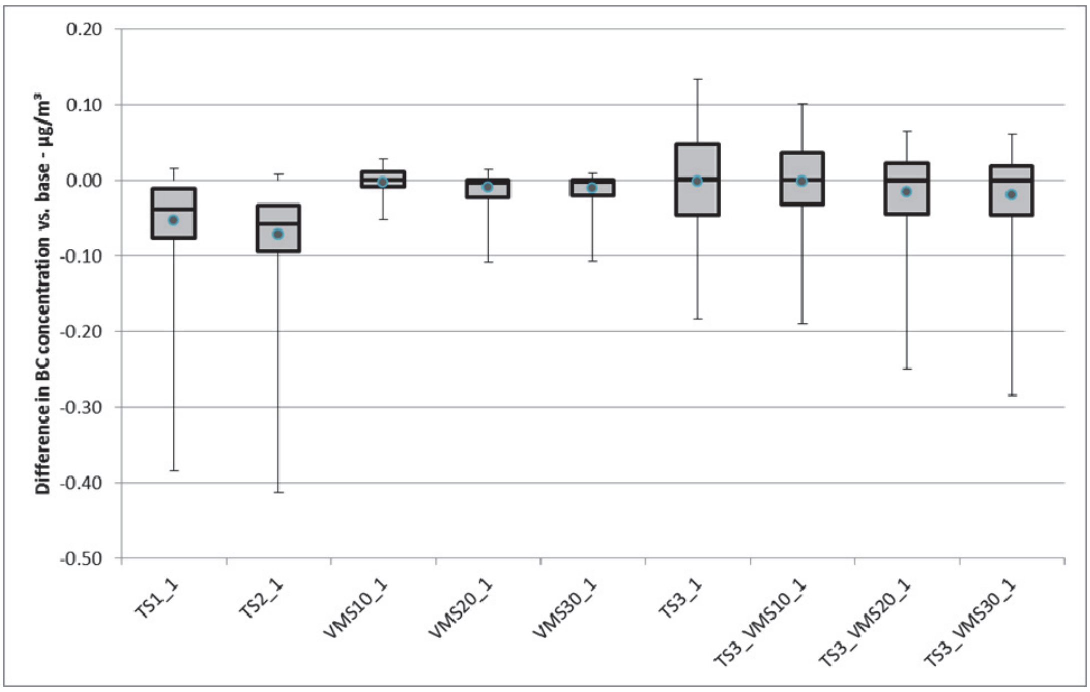

Figure 4: Boxplot of the BC difference respective to the base scenario. Location Byres Rd./ Uni. Ave, Glasgow. Boundary Condition 1, units: µg/m³.

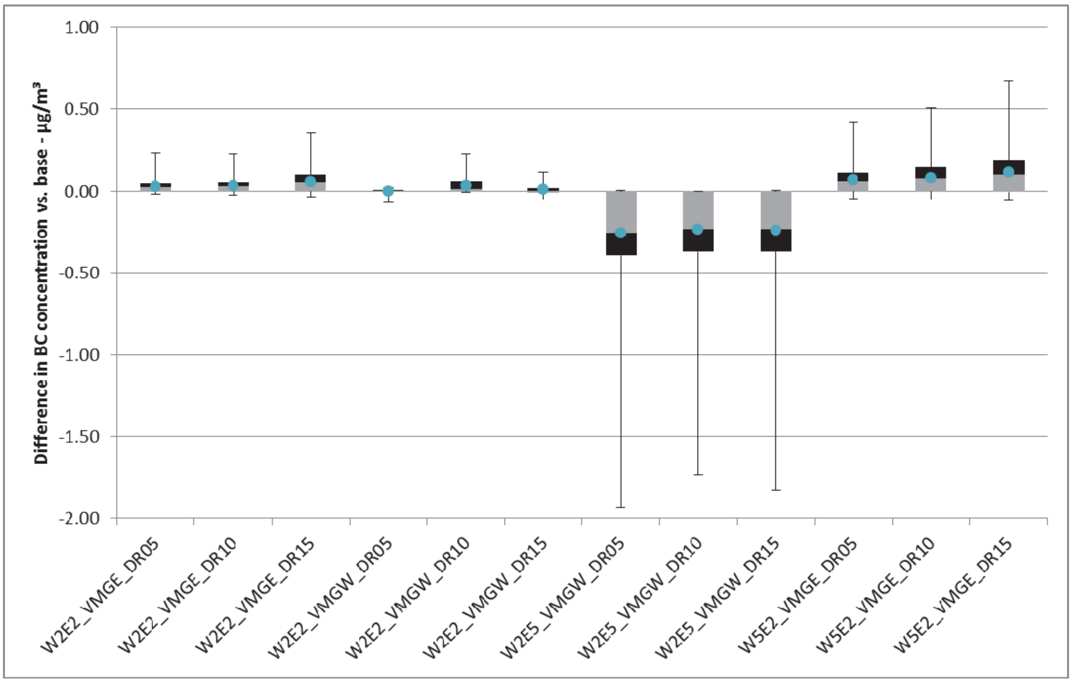

Figure 5: Boxplot of the difference in BC concentration vs. the base scenario, per ITS scenario, for BC monitor location 1, western arterial, Graz. Boundary condition 7:00 – 8:00, units µg/m³.

6. Conclusions

The potential impact of the CARBOTRAF DSS on air quality in both pilot cities is analysed using the simulation results. Implementation of ITS measures leads to potential changes in total BC emissions over the whole 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 on BC concentrations have large spatial and temporal variations. Overall, the best performing ITS measures have the potential to significantly improve the air quality at crucial locations. Averaged over the full test site effects remain fairly limited.

Acknowledgements

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