Field deployments of the MESSAGE system for environmental monitoring

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Version 4

[Robin North, Jeremy Cohen, Steven Wilkins, Mark Richards, Neil Hoose, John Polak][1]

[Margaret Bell, Phil Blythe, Bayan Sharif, Jeff Neasham, Visalakshmi Suresh, Fabio Galatioto, Graeme Hill][2]

[Iq Mead, Rod Jones, Alastair Beresford][3]

[Haibo Chen, Karl Ropkins, Paul Goodman, Colin Oates, James Tate, Narasimha Ballijepalli][4]

[1]Imperial College London, [2]Newcastle University, [3] University of Cambridge, [4]ITS Leeds

Preamble/credits:

The Mobile Environmental Sensor System Across GRID Environments (MESSAGE) project is a research project co-funded by EPSRC and the Department for Transport. The project was funded as part of the e-Science initiative with the aim of demonstrating that key outcomes from that programme could be deployed to address real world issues, in this case the detailed monitoring and management of air pollution from road traffic. It is a large project involving five universities; Imperial College London (Centre for Transport Studies, Dept. of Computing, Dept. of Electrical and Electronic Engineering, Dept. of Physics), University of Newcastle (Transport Operations Research Group, Dept. of Electrical and Computer Engineering, School of Computer Science), University of Cambridge (Dept. of Applied Mathematical and Theoretical Physics, Dept. of Chemistry, Computer Laboratory), University of Leeds (Institute for Transport Studies) and University of Southampton (Transportation Research Group). The project ran for 3 years from Oct 2006 with a budget of around £4M and involved more than 30 academic staff, postdoctoral researchers and PhD students. Additionally the project was supported in a variety of ways by 19 non-research organisations from industry and local government and overall co-ordination was provided by Imperial College London. More information can be found on the project website at www.message-project.org.

Introduction

Developments in sensing, positioning, communications and computing technologies have enabled the development of wireless sensor network technologies and their application to real world problems. In this paper we describe how the technologies developed in the Mobile Environmental Sensing System Across a Grid Environment (MESSAGE) project [1] have been deployed in a series of real world experiments to examine the relationships between transport and air pollution. Three different sensor systems have been developed to allow deployment on infrastructure, people and vehicles for both short and long term studies. The field trials conducted thus far have effectively demonstrated the use of these novel data collection and data management techniques to better characterise the distribution and variability of pollutants in urban environments as well as highlighting ways in which these technologies might be transferred to other application areas [2]. This paper describes the field trials conducted using each of the sensor systems in turn before offering a set of initial conclusions regarding their co-ordinated use in the management of transport and air pollution. Where appropriate, field trials were supported by additional deployment of conventional monitoring equipment provided by ITS Leeds and associated evaluation and cross-comparison work (not reported here) will be the subject of future publications.

Newcastle University deployments

Newcastle University developed a "mote" device designed to enable dense deployments in urban areas to allow continuous, minute-by-minute monitoring of the pollution distribution over an area. The devices are battery powered to facilitate simple installation and use a low-power, ZigBee-based communication protocol to route data between nodes and to a central gateway for backhaul to the data management system. Typically a network of sensors is deployed with sensors attached to street furniture (e.g. lamp columns and railings) with up to 80 metres between nodes.

The first deployment of forty static and ten dynamic sensors was carried out in Gateshead during August to December 2008 [3]. In parallel with these deployments, reference measurements were undertaken in conjunction with the University of Leeds Instrumented City facilities. The communications, software and sensor performance was fully tested. A series of on-street surveys enabled the functionality of different elements of the system to be demonstrated. The motes communicate with each other (up to five hops) using wireless (ZigBee protocol) relaying the data in real-time to a gateway. As a result of four months of deployment and evaluation, a new generation of the hardware and software was produced.

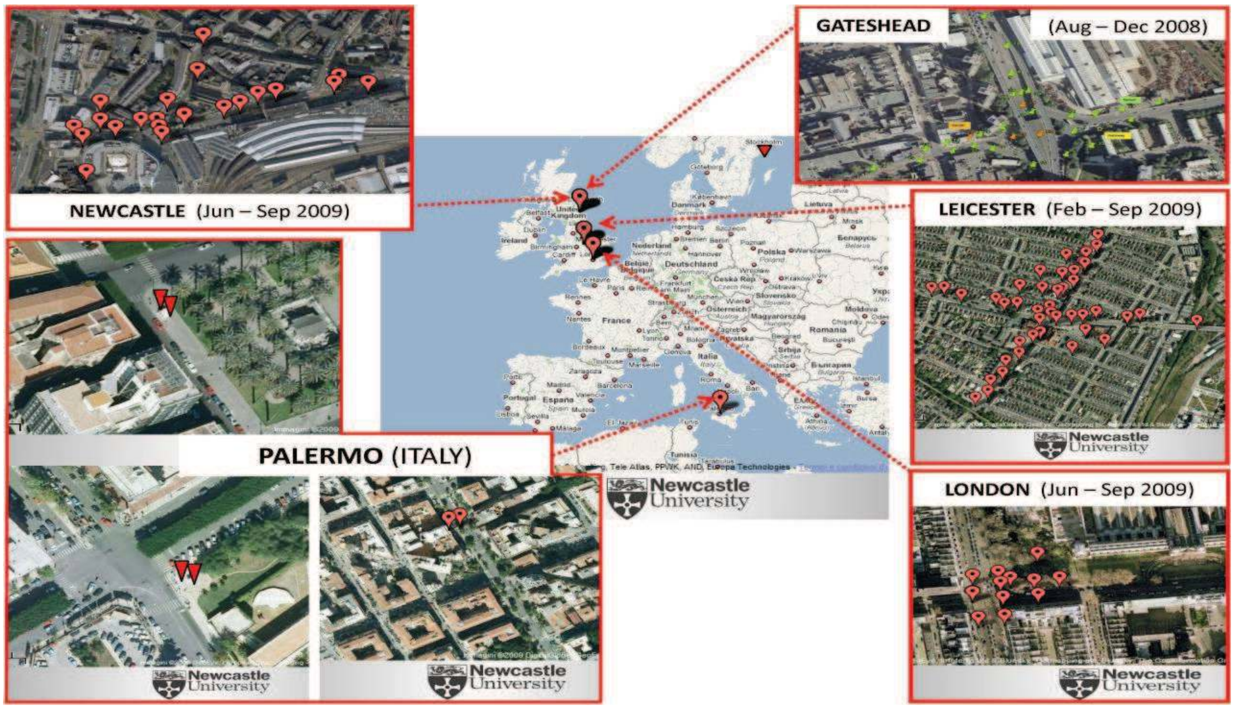

Figure 1 – Newcastle trial deployments of motes across UK and Europe (Google Maps screenshot content ©2009 Google - Map data ©2009 TeleAtlas; Imagery ©2009 DigitalGlobe, GeoEye, Infoterra Ltd & Bluesky, Getmapping plc, and The GeoInformation Group)

This addressed issues such as low communication performance (due to the characteristics of the built environment, such as grade separated junctions, trees, etc.); data calibration and validation; vandalism of sensors deployed at pedestrian levels; access to mains power for gateway. The transferability and scalability of the system was demonstrated in other UK cities. In Leicester, the largest array of 50 motes was deployed in the period February – September 2009 across an area of about 1km^2 shown in Figure 1.

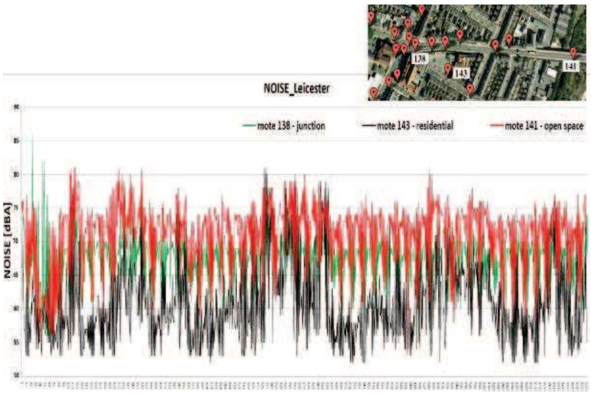

Figure 2 - Noise measurements between different areas (Google Maps screenshot content ©2009 Google - Map data ©2009 TeleAtlas; Imagery ©2009 DigitalGlobe, GeoEye, Infoterra Ltd & Bluesky)

Figure 3- Autonomous Zigbee-GPRS gateway mounted on a lamp column in Leicester

In Leicester, due to the unavailability of a secure streetside location with mains power and Internet access, an autonomous gateway (Figure 3) was designed. The gateway is mounted at a high level on a lamp column to gain access to mains power from the lantern and uses GPRS to provide wireless communication via the Internet to the remote server (in Newcastle University some 200 miles from Leicester). Leicester was chosen as a demonstration site because the wealth of historic data collected since 1987 enables the features of the MESSAGE data warehouse to be demonstrated. Also, it has an air quality management system, Airviro, which uses both real-time traffic data (from SCOOT) and meteorological conditions to produce “nowcasts” and “forecasts”. The street canyon pollutant predictions from the Airviro model for the 50 mote locations are brought to the server as a web service to enable correlation with measurements.

The scalability and flexibility of the modular mote design to enable simultaneous measurement of traffic, carbon monoxide (CO), nitrogen dioxide (NO_2) and noise allowed relationships between these measurements to be investigated. Figure 2 shows how the noise levels change substantially depending on location whether at a congested junction of a tertiary route, mid-link of a secondary road or in a residential street

A high degree of operational stability and scalability has been demonstrated with further deployments in Newcastle (where data capture is integrated with real-time traffic data from SCOOT); in London in South Kensington close to the Natural History Museum and at three sites in Palermo (Italy) (see Figure 1). In Newcastle, a network of 30 motes was operated for nearly 4 months; in Gateshead, 30 static motes were operated for 5 months and supplemented by 10 mobile motes for a two week survey; in London, a network of 12 motes operated for 3 months in conjunction with the co-ordinated system trials; in Leicester, 50 motes operated for 7 months allowing investigation of the impacts of changes in traffic levels and in Palermo, a set of 3 motes were installed at two different air pollution monitoring cabins for two weeks during each of Winter, Spring and Summer. This was then supplemented by a pair of motes installed for 3 months in the vicinity of a major road.

During the trial deployments described, Newcastle University tested approximately 130 sensors and the robustness and reliability of the Newcastle MESSAGE system architecture. Sensor operation has been verified over the temperature range -9 to +38°C. Successful operation has also been proven in an indoor, factory environment and an upcoming deployment in India (November 2009) will provide a broad spectrum of representative operating environments. We are confident that the technology is applicable to most outdoor and indoor environments worldwide.

Cambridge University Deployments:

The UCAM air quality sensor units are lightweight hand held systems containing all the electronics necessary to operate selected gas sensors along with position and transmit the collected data. Four types (A-D) were developed to investigate different aspects of the technology [1]. The design was optimised for portability to enable mass deployment using pedestrians and cyclists as mobile environmental probes.

The sensor units have been deployed on a number of occasions in Cambridge, London, Valencia and at Cranfield airport. The most recent deployment in Cambridge was composed of approximately 40 sensors deployed multi modally for approximately 3 hours in August 2009. The sensors were a mix of A, B, C and D sensors deployed using pedestrians, cyclists, motorists and at static sites alongside Cambridge Council monitoring sites. The coverage for the deployment is shown in Figure 4, a plot illustrating nitric oxide (NO) and NO_2 concentrations with height as a proxy for concentration. Figure 5 shows similar datasets collected in Central Valencia with 8 sensor units and London with a single sensor unit over a period of several hours.

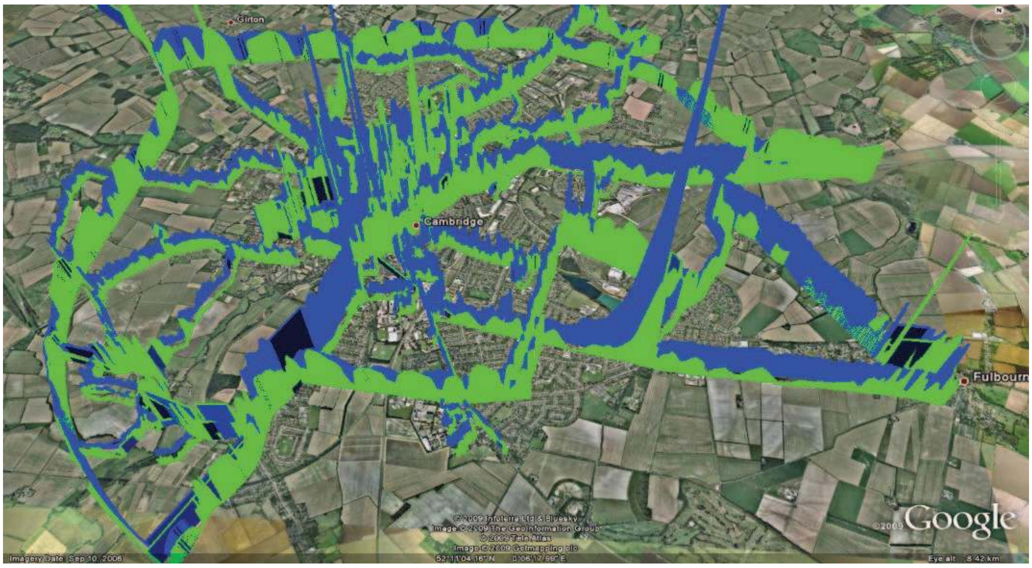

Figure 4: NO (Blue) and NO_2 (Green) concentrations variation across Cambridge. (Google Earth screenshot content ©2009 Google - Imagery ©2009 Infoterra Ltd & Bluesky)

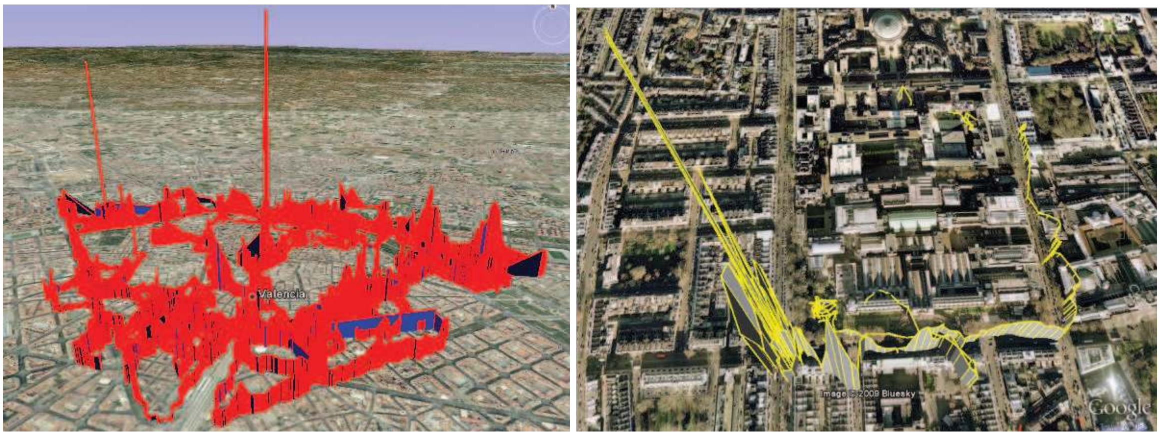

Figure 5: CO data in central Valencia (Google Earth screenshot content ©2009 Google - Imagery ©2009 TerraMetrics and Data – SIO, NOAA, US Navy, NGA, GEBCO) and South Kensington, London. (Google Earth screenshot content ©2009 Google - Imagery ©2009 Infoterra Ltd & Bluesky)

These plots are a "snapshot" of the levels of the measured air quality gasses in the deployment areas. The Cambridge mass deployment dataset alone incorporates approximately 100,000 measurements which highlights the need for sophisticated computing systems to support widespread data collection of this type [1]. The data from these deployments is in the process of being analysed in detail. What is immediately apparent is that there is a large degree of variability across the urban environment both temporally and spatially.

The sensors were also deployed using a different method at Cranfield airport. Cranfield airport is home to the UK Facility for Airborne Atmospheric Measurements (www.faam.ac.uk) large atmospheric research aircraft (a modified BAe-146 aircraft). As part of the OMEGA research project (www.omega.mmu.ac.uk) an array of Cambridge MESSAGE sensors was deployed at the start of the runway. The aim of the experiment was to capture data related to the aircraft engine exhaust plumes as the BAe-146 took off. Figure 6 shows a time series where the eight take off episodes are clearly marked by increased NO_2 concentrations.

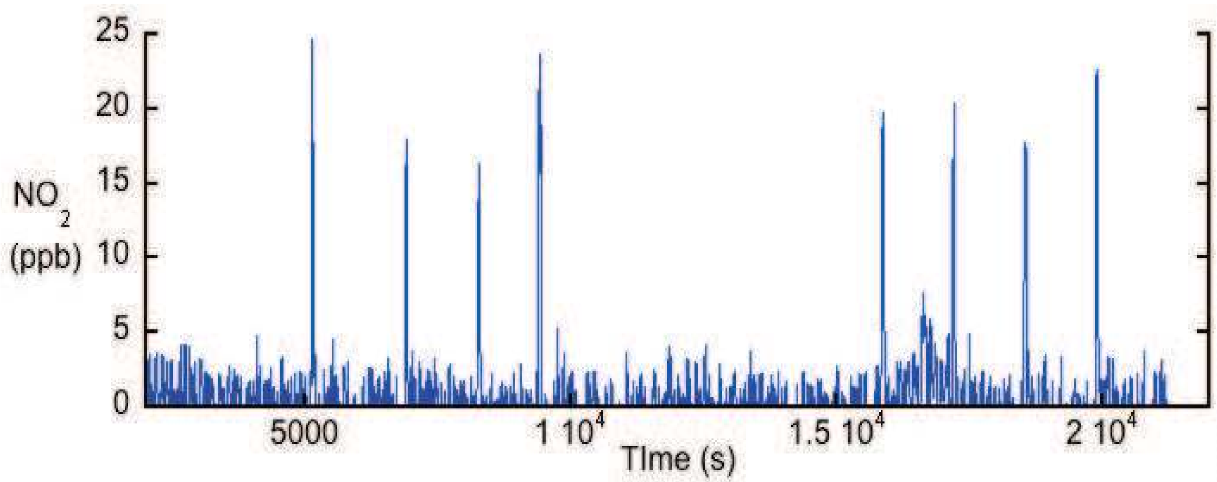

Figure 6: Data series taken at Cranfield Airport.

A total of over 50 sensors have been deployed and tested. These deployments have demonstrated how large numbers of low cost sensors can be deployed in a co-operative manner to capture a snapshot of the pollutant distributions across an area. This capability helps to identify areas of the city where further investigation is desirable and can help to prioritise interventions for effective air quality management.

Imperial College London

Within the MESSAGE Project, Imperial College led on the development of a novel, compact design, mobile/portable multi-species gas analyser to complement the low-cost electrochemical sensors used in the Cambridge and Newcastle units. A college spin-out company, Duvas Technologies Ltd was set up over the course of the project [5]. The developed devices employed a variant on Differential Ultraviolet Absorption Spectroscopy (DUVAS), itself being a derivative of Differential Optical Absorption Spectroscopy (DOAS). DOAS originally stems from atmospheric physics research, where the analysis of narrow-band absorption features overcomes the need for calibration and provides an absolute measure [6]. Moreover a number of key pollution species absorb in the UV, and the instantaneous spectroscopic technique provides a high degree of selectivity. This technology was selected as appropriate for vehicle mounting due to its robustness, and instantaneous response time when coupled with a high throughput gas chamber.

The sensors provide high resolution real-time measurements of a range of species including oxides of nitrogen (NO/NO_2), sulphur dioxide (SO_2), ozone (O_3) and benzene (C_6H_6) at part per billion levels. The field units were developed for mobile deployment [4] with the objective of providing high time/spatial resolution measurements across a wide area.

Initial deployments in December 2008 demonstrated potential to gather data from probe vehicles across long trajectories and in the process to identify localised hotspots (see Figure 7). A set of further tests were then conducted around a test site in South Kensington (Figure 8) where the same circuit was driven repeatedly using two vehicles to identify whether mobile probes could be used to capture the temporal variability in pollution levels at a given location. These results suggested that while there is a high degree of variability between individual trajectories, the mean values over the course of an hour, and the average spatial distribution of pollution measured by the two vehicles was very similar.

Additional tests were conducted to investigate the potential for ad hoc wireless communications between sensors and infrastructure nodes, in particular multi-hop data buffering techniques during intermittent communication regimes. This was found to be effective, although the vehicle dynamics and the consequent node topology have a strong bearing on the connectivity of the network.

A set of DUVAS units were adapted for use as portable reference units running on batteries and were carried around the test site by pedestrians and cyclists [7]. Extended sampling at a single location allowed the temporal variation to be captured. This is shown in Figure 9 where a unit was deployed near the centre of a busy intersection. The periodicity in the measured values is seen to correspond to the traffic signal timings (~48 seconds per cycle) with the relationship between NO and NO_2 also clearly observable. Figure 10 illustrates a comparison between two identical units carried along a main street and junction. Units were carried approximately 1m apart for the initial phase, and then separated at curb-side after a street crossing to make the synchronised comparison between curb and street-side approximately 10m apart.

In total, six mobile DUVAS units were developed and deployed in a range of contexts, including extended deployments adjacent to an air quality monitoring station and on a training bus moving around South London. Collectively these deployments have demonstrated a new capability to capture high resolution pollution data across wide areas using mobile probes. The spatial and temporal variation in the data is also clear, and will form a focus of continued research activity in this area.

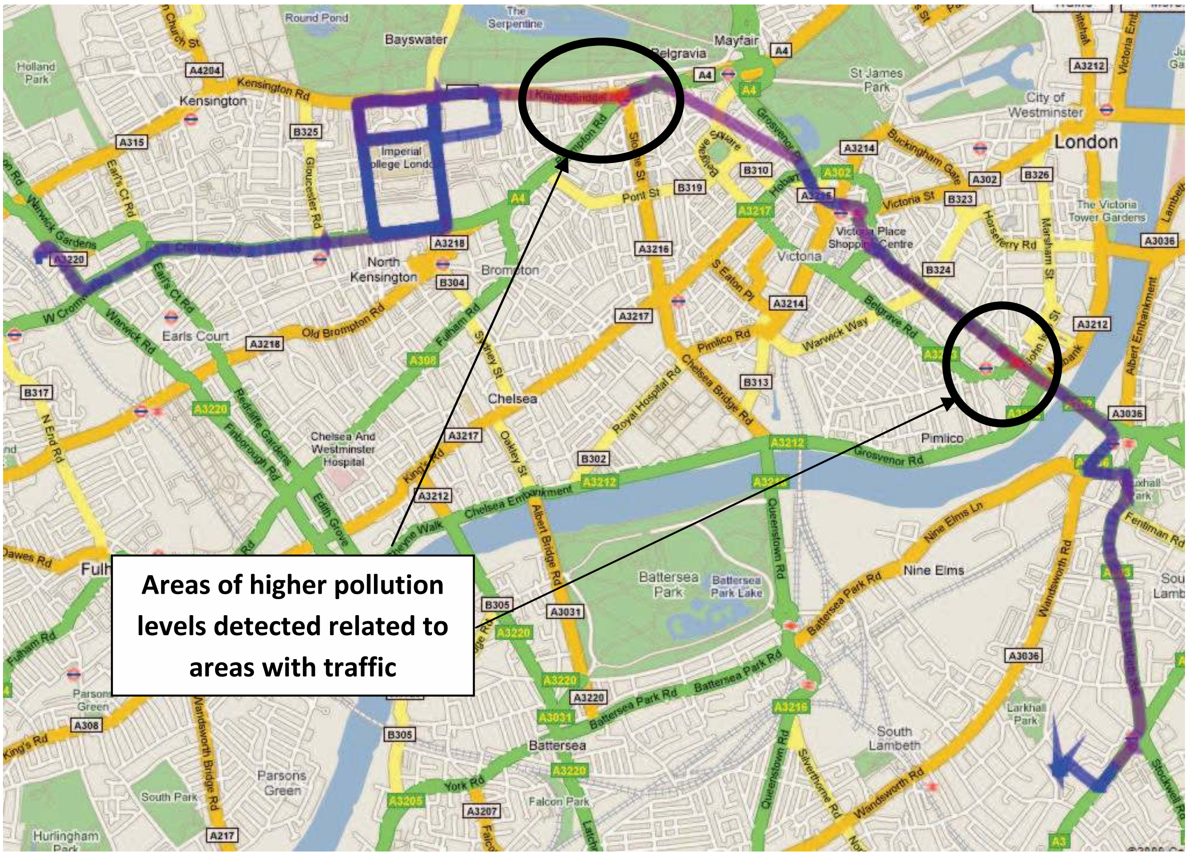

Figure 7: Vehicle-based sensor measurements across London, December 2008 (Google Maps screenshot content ©2009 Google - Map data ©2009 TeleAtlas).

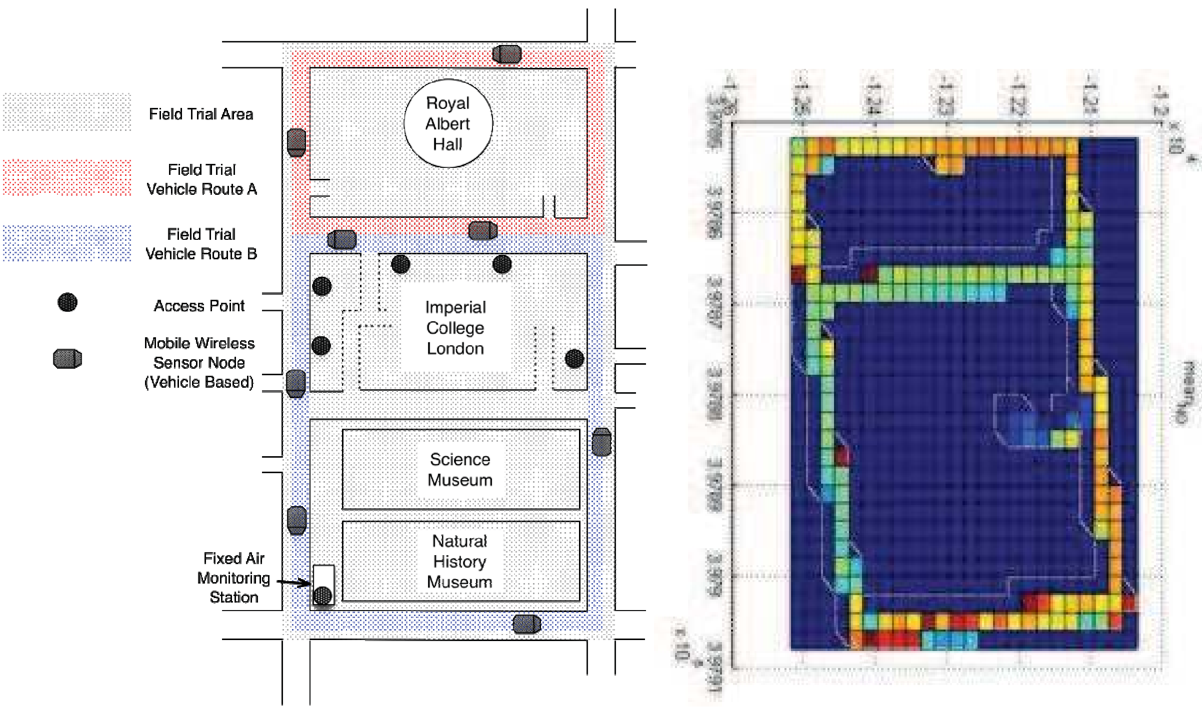

Figure 8: Test site in South Kensington, London and sample data for NO

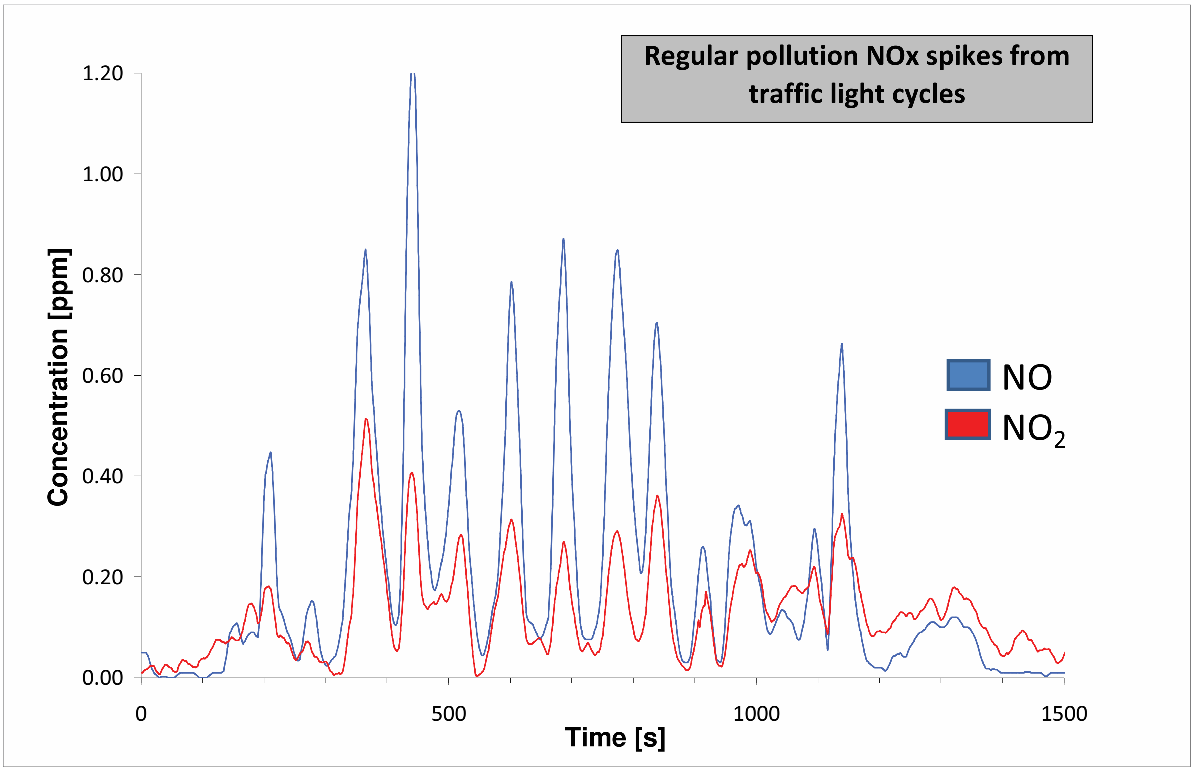

Figure 9: Periodic peaks in pollution levels in the middle of a busy arterial road from a static unit [7]

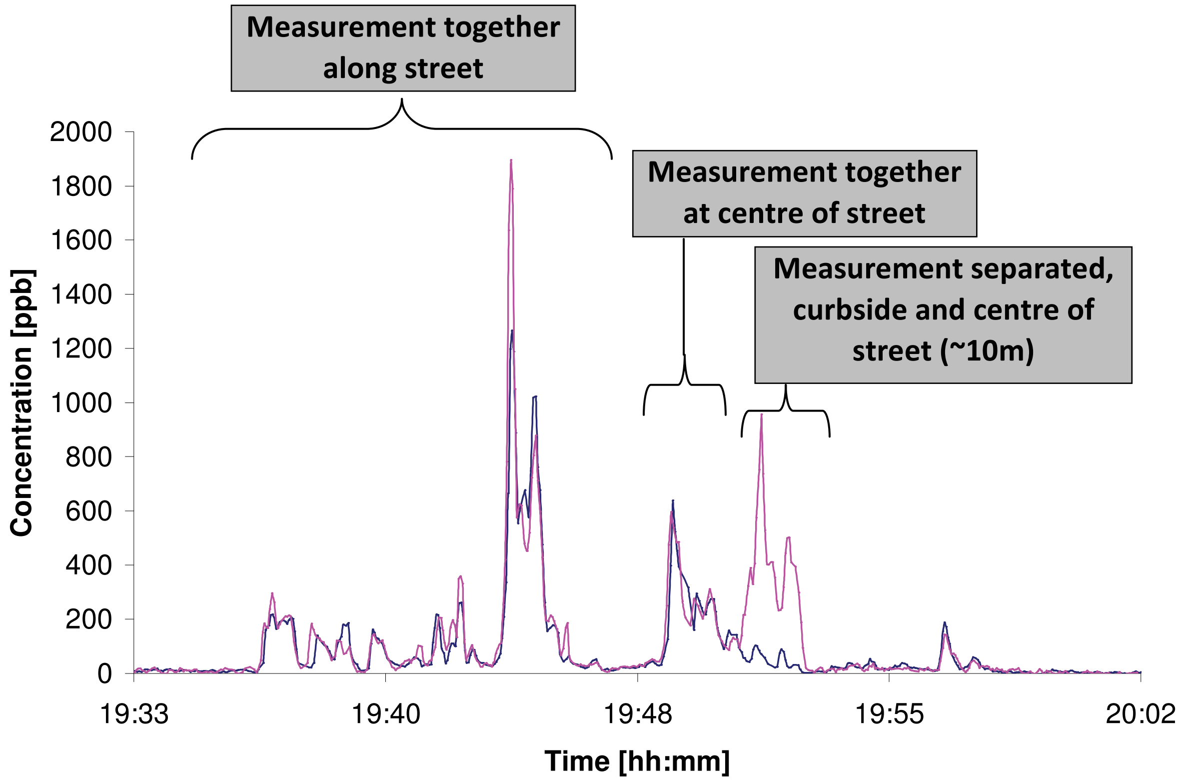

Figure 10 Comparison of measurement of NO using two portable Duvas units being carried along street [7]

Summary and conclusions:

The MESSAGE Project has successfully developed and demonstrated a set of techniques to dramatically increase the resolution with which the spatial and temporal distribution of urban air pollution can be measured. The field trials described in this paper illustrate the range of possibilities, with the three different sensor systems offering complementary capabilities in terms of identifying areas of concern, investigating the mechanisms in detail, and providing long term monitoring to support traffic management interventions.

The three sensing systems developed in the MESSAGE project were designed to integrate with a common architecture for data management, processing and display. To effectively demonstrate these capabilities, a co-ordinated deployment was implemented in London as part of the MESSAGE Project demonstration day on 30th June 2009. This included the deployment of additional instrumentation from the ITS Leeds Instrumented City facility to provide additional reference baselines. Results were positive, with data from 25 sensors being transmitted to multiple users for real time display and analysis.

The current datasets indicate relatively large differences over a short distance/time periods and therefore both higher spatial and temporal resolution could provide more information and insight of the nature of pollution and exposure. The technologies developed in MESSAGE can further provide the data necessary to improve management of transport and reduce its environmental impacts through quantifying the real world impact of different interventions. These technologies also open a range of opportunities in other application areas. These applications are considered in more detail in [2] and in on-going research that builds on the MESSAGE developments.

References

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