Development of decision support tools for assessing the significance of exposure of athletes to air pollution: A Scoping study for Scottish Government

by the University of the West of Scotland and Imperial College, London

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Summary

This pilot study reports the results of work to evaluate the potential of the application of open source GIS-based software tools for the spatial prediction of individual exposure to air pollution. The context of this work is in relation to the potential impact on performance of elite athletes exposed to air quality in the Glasgow area. It assesses the viability of a decision support tool (DST) linking athletic performance and air quality with the intention to provide support for planning of low exposure routes for training and competitive events, specifically in relation to the Commonwealth Games in 2014 and more widely in the long term management urban environments.

In the absence of suitable GIS emission inventory we provide details of the application of the decision support tool based on a coarse scale 2001 PM10 land use regression model for the UK developed by Imperial College London and others. The tool was developed to provide the ability to search and select routes of low exposure across Glasgow and further development of functionality has been identified. This development is limited by the absence of up to date, high resolution emission models for particulate matter in the Glasgow area.

Primary data collection of personal exposure to black carbon (using a personal aethalometer device), to investigate the link between air quality and athletic performance was undertaken for a small cohort of elite athletes training in the Glasgow area. A number of training sessions were assessed between January-April 2012 in north Glasgow, and average suburban exposure levels between 1,500 and 3,600 ng/m^3 were obtained for ~hour long evening training sessions. These levels compare to 4,000-5,000 ng/m^3 average exposure for cyclists during afternoon peak traffic in the training area and 7,000 – 9,000 ng/m^3 average exposure during a suburban car commute in evening rush hour traffic. The statistical validity of comparisons between BC exposure and athlete performance was limited by the number of consistent recruit performance data-exposure pairs, but appeared that there may be a measureable link between peak ventilation flow and blood O_2 even at low exposures and requires further exploration.

The pilot study also identifies a tangible and cost effective opportunity to provide full functionality of the DST and protocols. It identifies directions for further data collection to provide robust statistical assessment of the link between athletic performance and air quality.

Background

Air quality during athletics events has become of concern surrounding summer Olympic events in Athens (2004) and Beijing (2008) with some evidence to suggest that performance of both long and short distance running may be impaired by air quality (see Wang et al, 2008; Li et al, 2011). This project is a proof of concept study to investigate the potential for a GIS (Geographical Information System) based personal (air pollutant) exposure model to be adapted to allow planning of low exposure training and event routes. In this instance it has focused on training purposes for elite runners with potential application to planning events such as running routes for Commonwealth Games event in 2014. It is based on the adaption of software developed during EU FP7 projects (http://www.genesis-fp7.eu/) and supported by protocols developed to recruit volunteers and collect personal performance and air quality exposure data to provide an opportunity to investigate the link between air quality and performance.

Aim:

To develop a methodology for assessing the exposure of athletes to air pollution

Objectives:

1) adapt the STEMS tools developed in GENESIS for application in the Glasgow area;
2) undertake a pilot study to collect information on running routes, time-activity patterns, and breathing rates of athletes in the Glasgow area;
3) use these data to estimate the variability of athletes' exposures and then help plan low exposure running routes;
4) demonstrate the use of STEMS to plan routes for different events in the 2014 Commonwealth Games in Glasgow which avoid areas of potentially high air pollution.

Methodology

a. Development of GIS pollutant exposure model

This is based on the extension of open source personal air pollution exposure assessment software system developed during the EU FP7 funded GENESIS project which UWS/Imperial College team contributed to (2008-2011). The extension investigated the integration of local air pollution surfaces and transport models for the Glasgow area as potential inputs to refine the tool for specific local application. Activity in this section included meeting with Air Quality team of Glasgow City Council and planning officers from Strathclyde Passenger Transport Executive. Software development and GIS integration was undertaken at Imperial College. A report on the development is included in the results below.

b. Recruitment and Collection of athletes' air quality exposure and performance data

This part of the study involved the identification and recruitment of a target of 20 elite (marathon) runners (50:50 M/F) through local running clubs and their participation in a series of training sessions (target 1 hour duration) across urban/rural areas to enhance potential air quality contrast.

The study was undertaken with participant's full consent. Copies of the consent form and a completed health history questionnaire were collected and stored. Examples are provided in the Appendices. For each individual recruit, breath volume and heart rate were measured before and after training sessions.

Air quality was assessed using Black Carbon as an indicator. A real-time aerosol black carbon personal exposure measurement device (microAeth® Model AE51, aethalometer, set at 60 second integration time), was used to collect exposure information during each of the training sessions. The device was carried by a volunteer who cycled with the training group. In addition, a number of broader contextual runs were completed where the device:

1. Was used to monitor road-level exposure during an extended car journey across Glasgow city centre. The sampling tube of the device extended through the rear passenger window approximately 1 m above ground.
2. Produced monitoring data for a circular route around one of the training circuits. This was over a period of 4 hours, working up to the evening training session. This route intersected heavily trafficked roads/junctions and lower traffic residential areas.

Plots of routes and monitoring data are provided in the appendices, summary results are provided below. The wider air quality context was assessed in comparison to local authority air quality monitoring station data (from http://www.scottishairquality.co.uk/) identifying PM_{10} levels across training session dates for comparison to black carbon personal monitoring.

Results and Discussion

Decision support system for selection of 'low' air pollution exposure routes

Overview

We have adapted "personal exposure modelling" tools developed as part of EU FP7 funded GENESIS (GENeric European Sustainable Information Space for environment) project (UWS and Imperial; 2008-2011) to provide a prototype decision support system for the Glasgow area with two main functions:

1) For individuals to be able to select low(est) exposure routes radiating from a particular location (i.e. address or postcode) to aid in the planning of training routes;
2) To compare air pollution exposures on pre-defined routes to assist in planning for athletes' training or staging athletics events (e.g. Commonwealth Games marathon).

This section describes the piecemeal steps in executing the prototype software with corresponding screenshots for 1) and 2) above.

The prototype is developed within ArcGIS 9.3. For demonstration purposes, the user interface and geospatial functionalities are coded using its embedded VBA environment.

We have incorporated into the GIS digital data on the road network (Ordnance Survey), data on population represented by 2001 Postcode (Ordnance Survey) locations (points), a digital terrain model (Ordnance Survey) to calculate slopes along routes, and a modelled long-term (i.e. annual) surface of particulate air pollution (PM_{10}) extracted from a national (Great Britain) model of PM_{10} at 100m pixel resolution developed by colleagues at Imperial (Vienneau et al. 2010). We originally intended to develop high resolution (i.e. 20 metre grid) air pollution surfaces for the Glasgow but it was not possible during this project to obtain digital information on traffic flow and speed characteristics from local authorities (GCC; SPT) in order to generate an emissions inventory. As far as we are aware, the Greater Glasgow area does not have any air pollution modelling capacity.

Pre-processing of data

As a one-off pre-process, the transport network (represented by line features) is intersected with the air pollution surface(s) to attach "exposures scores" to different parts of the network (Figure 1). For this demonstration the transport network is broken at 100 metre intervals (i.e. resolution of the PM_{10} surface). The series of steps used for the attachment of exposures scores is shown in Figure 1. Improvements in the resolution of modelled air pollution surfaces could be achieved with the development of a local air pollution model (i.e. Greater Glasgow).

'Network Analysis' functions in ArcGIS are then used for generation of routes. The route selection becomes a function of the series of exposures scores (i.e. cost or impedance) along the transport network defined by discrete point locations (see Figure 2). Each point location is associated with a road, has a value for slope (dependent on direction) and an exposure score.

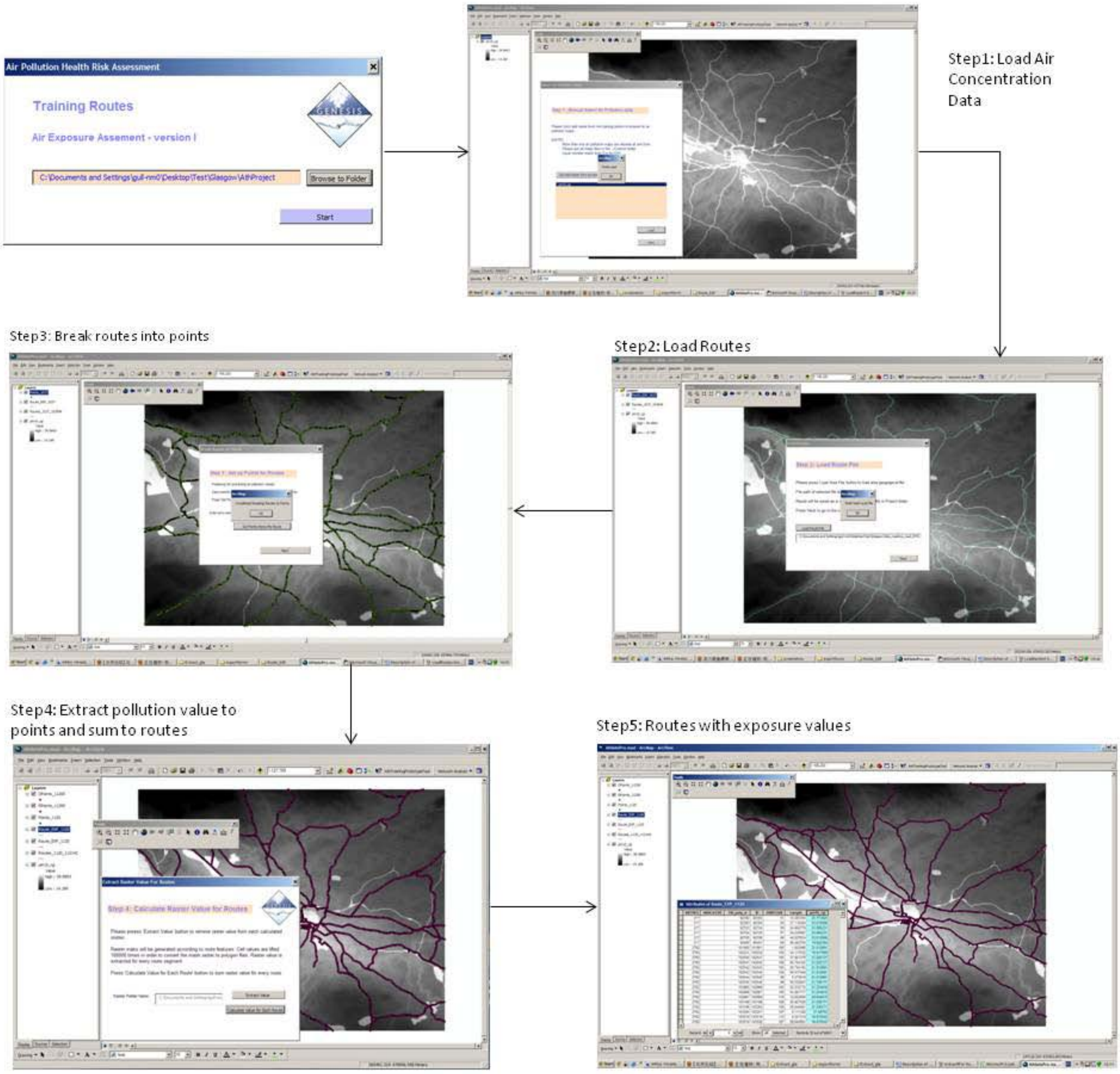

Figure 1. Pre-Process of extracting air concentration values to the transport network

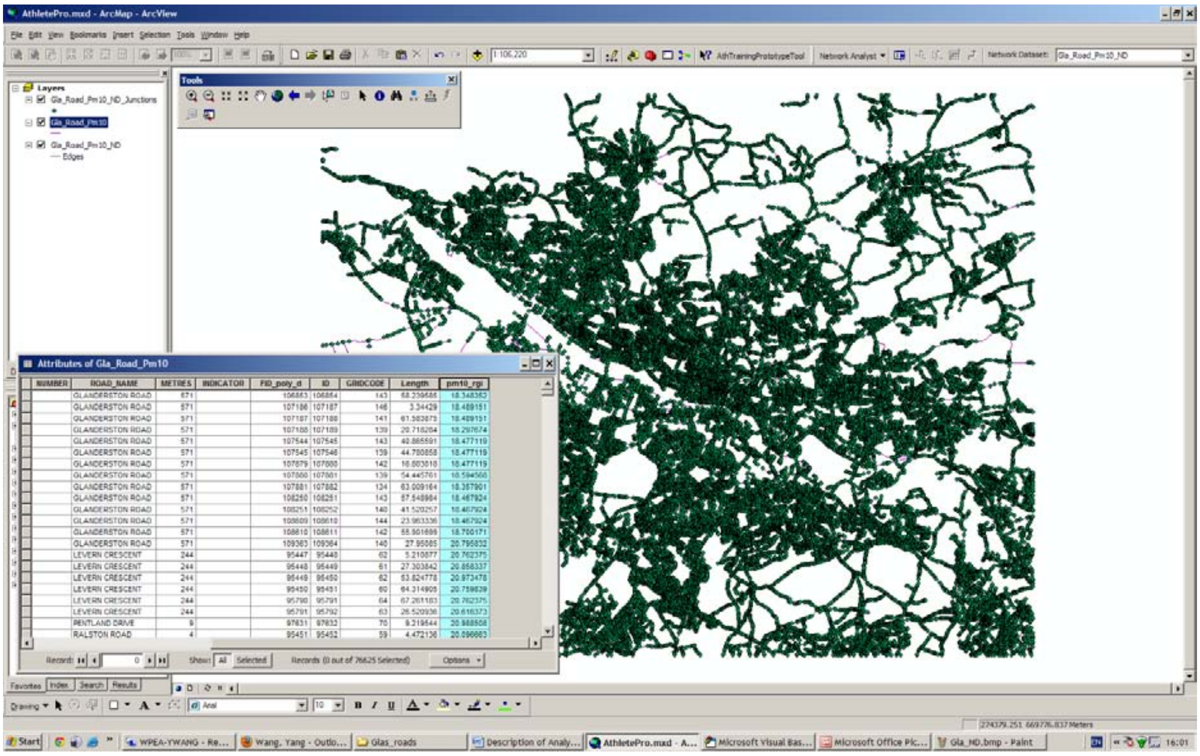

Figure 2. Point-based transport model for Glasgow

Loading the DSS and selecting the mode of analysis

Load the ArcGIS project in Windows Explorer and start the prototype by clicking the 'AthTraniningPrototypeTool' button on the Manu bar as shown in Figure 3. A start analysis form will pop up for an analysis project folder path.

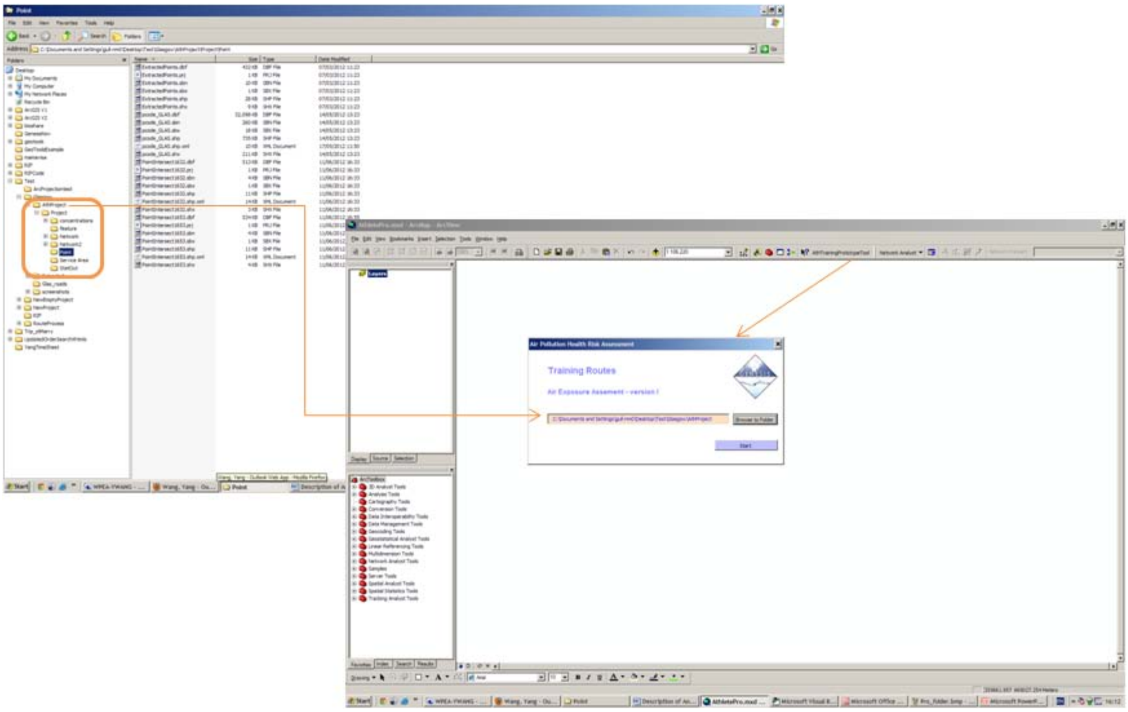

Figure 3. Start Analysis and Specify Project Path

After loading the project folder path, the following switch board (Figure 4) appears. It offers the user a facility to choose whether to perform 1) network analysis to select a route, or 2) calculate the exposures across a pre-defined route.

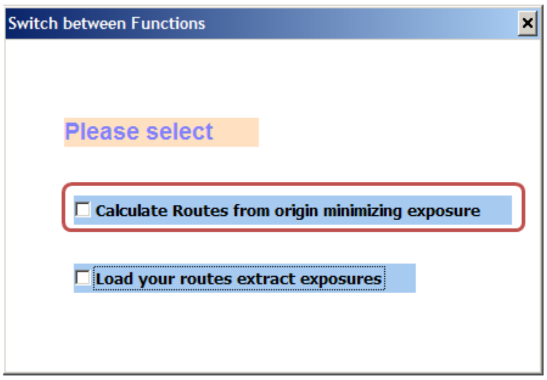

Figure 4. Choice of analysis

Part I: Training route selection

In this section, we focus on the first option. Several steps to execute this analysis are outlined below. The screen-shots were taken from ArcGIS at each stage in the process.

Routes are calculated between origins (O) and destinations (D) represented by postcodes. A separate point shape file holding all postcode locations of Glasgow is held in the GIS. The postcodes can be replaced by any point file, for example centroids of an area (e.g. Census Output Area) or other point locations (athletics clubs, address locations etc.). Figure 6 shows the coverage of the O/D locations for the Glasgow area.

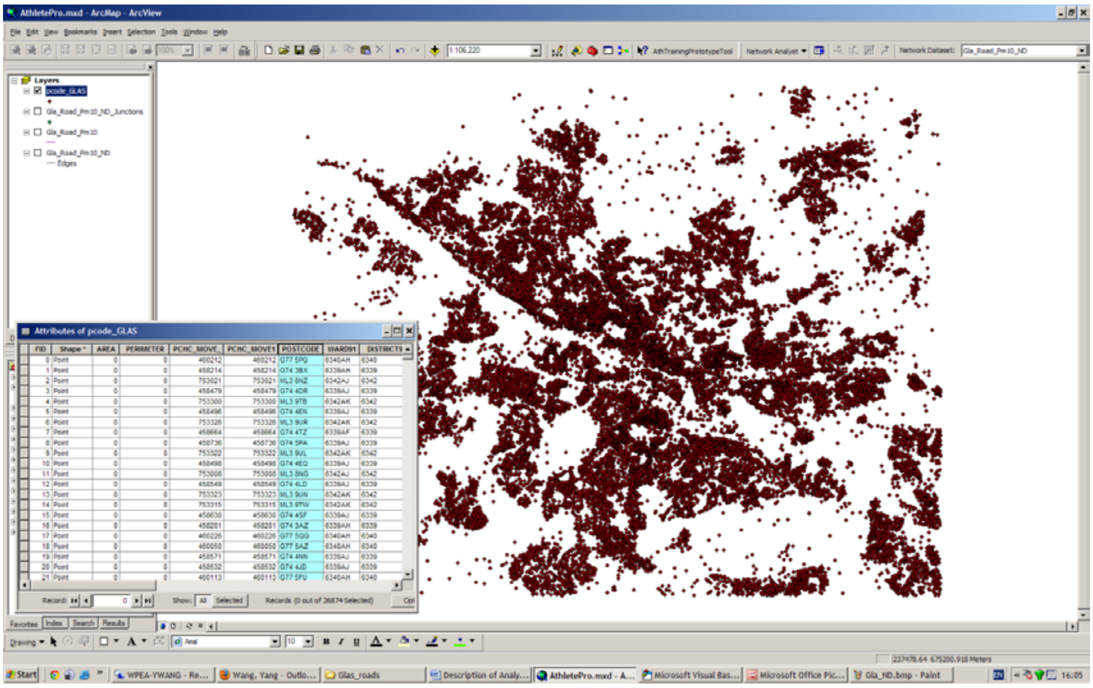

Figure 5. O/D Postcode locations in Glasgow

Step 1:

Navigate to project folder and load in O/D point file (i.e. postcodes). Glasgow postcode geography is placed in PROJECTPATH\Project\Point\pcode_GLAS.shp. Figure 7 shows the loaded Glasgow postcode locations.

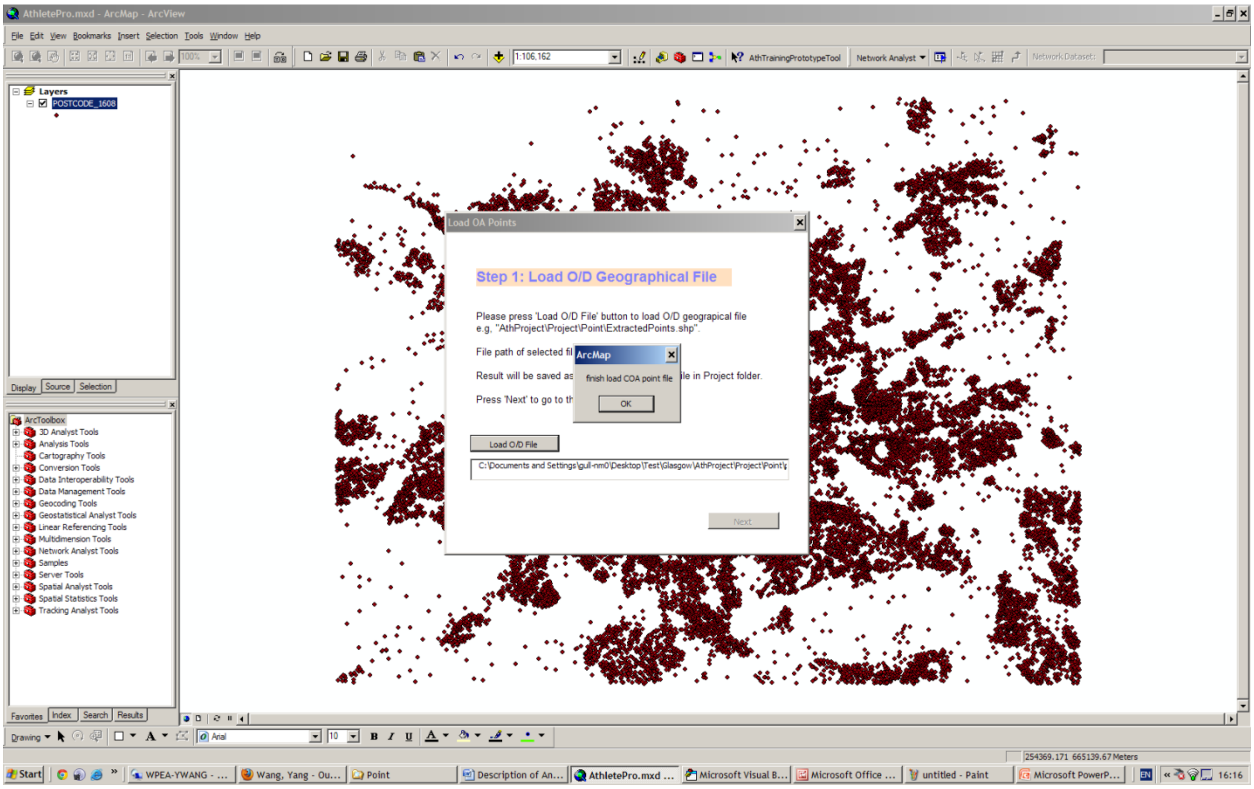

Figure 6. Load in O/D file from the project folder

Step 2:

The user is prompted to provide a start location by entering a postcode. The user is also asked to specify either a total length for the route (in this case 10km or 20km) or a total running time. Here we invoke the 'calculate service area' tool in ArGIS to find all of the accessible streets located within the specified distance or time from the start location, using an "out and back" approach. The result of this step is a service area (represented by a polygon in the GIS) which covers all the streets satisfying the training distance criteria. The transport network and air pollution surface are then automatically loaded into the project. Figure 7 shows the modelled PM_{10} surface along with the postcode locations, transport network, and service area based on the chosen distance/time from the specified postcode – in this case 'G20 6HQ' as origin and 10km as training distance.

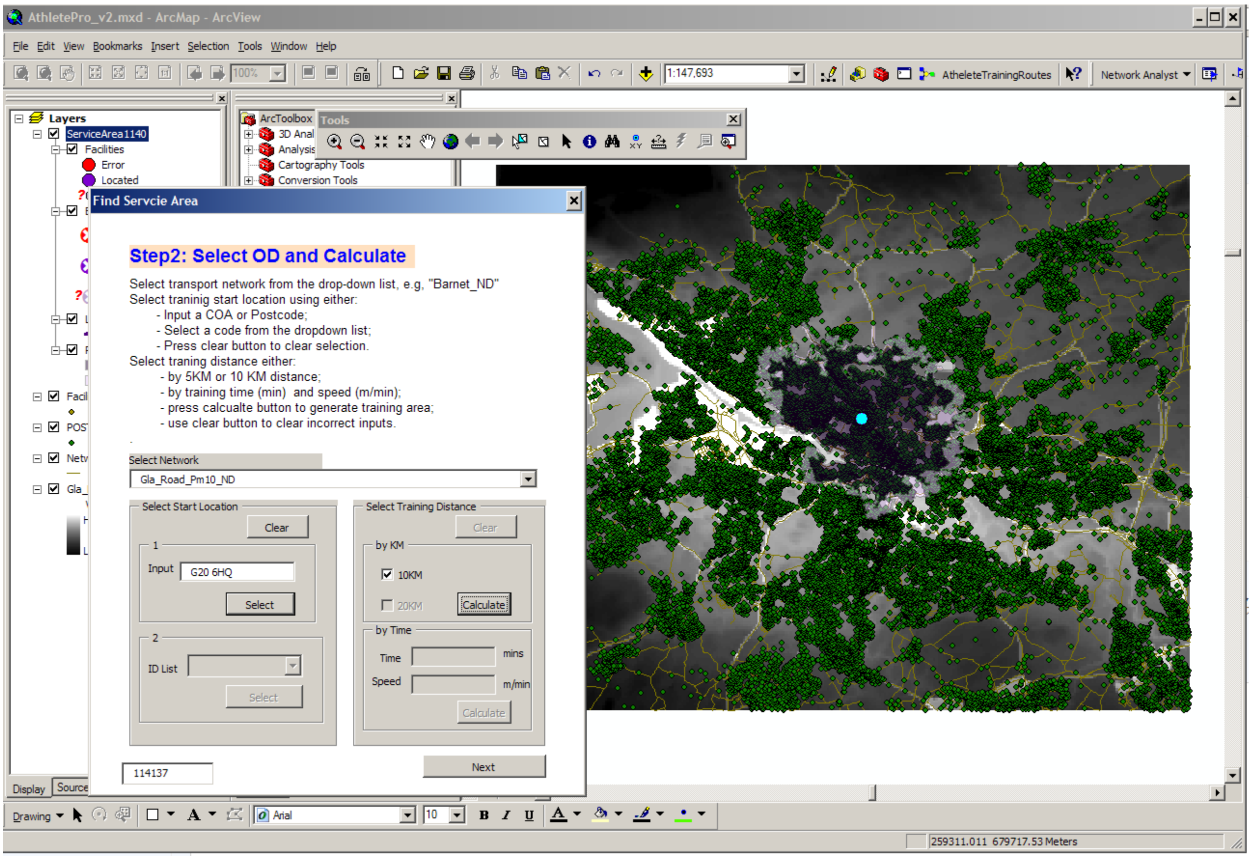

Figure 7. Calculating the service area

Step 3:
This step firstly selects all the COA points (n.b. other data could be used, such as the same postcode file used for origins, address locations etc.) falling within the service area as possible destinations. In normal operation the software will find routes based on exposures but it is also possible to specify length. The tool (Figure 8) will load in a 'closest facility' layer, set the specified training origin and find all the possible destinations meeting the distance/time criteria. It is possible that no routes matching the exact distance/time criteria will be found so a tolerance (i.e. within 10% of the chosen distance or time) is used in route selection. The current version uses an "out and back" approach so the route length is half the specified total training distance/time.

In future development, we would implement "looped routes" and routes where the user can specify a number of "way points" (e.g. via the park, via Easy Street etc.).

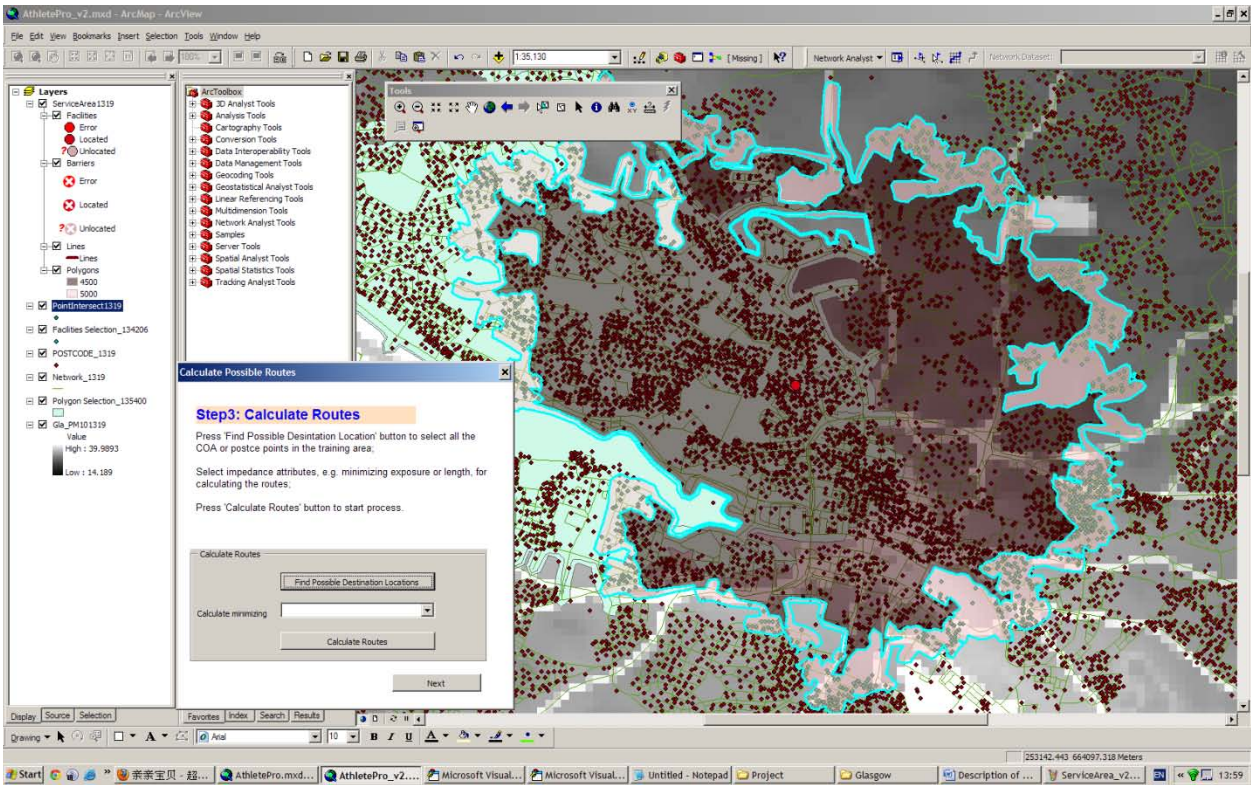

Figure 8: Calculating of Training Routes Satisfying Specified Criteria

Step 4:
The final step allows the user to select one or more routes matching the selection criteria, ranked in ascending order of exposure scores (see Figure 9). By default, the route with the lowest average exposure will be selected that meets the distance/time criteria. Other routes from the list of lowest ranking exposures can also be displayed. At present the tool works on a flat world but in a future revision we would account for slope along routes in calculating exposures based on ventilation rates (using values of ventilation for different exercise rates from the literature).

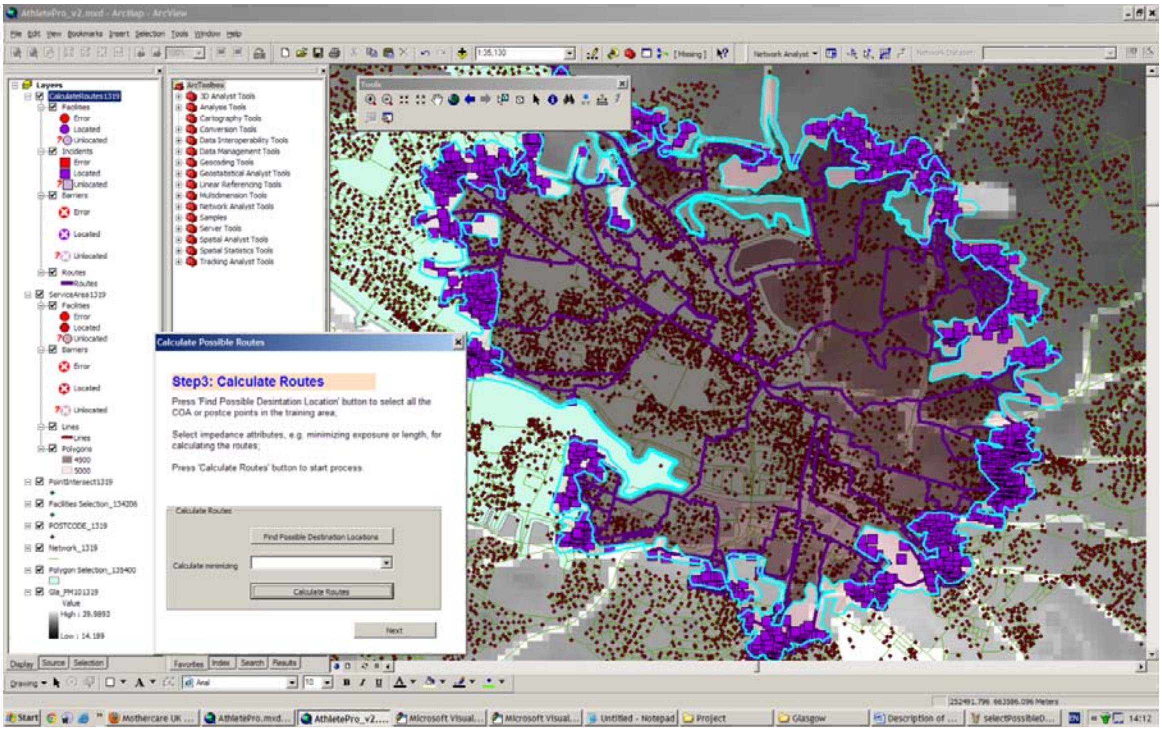

Figure 9. Selected route

Users have the option to export information (e.g. road names) on the selected routes to external Excel file (Figure 10).

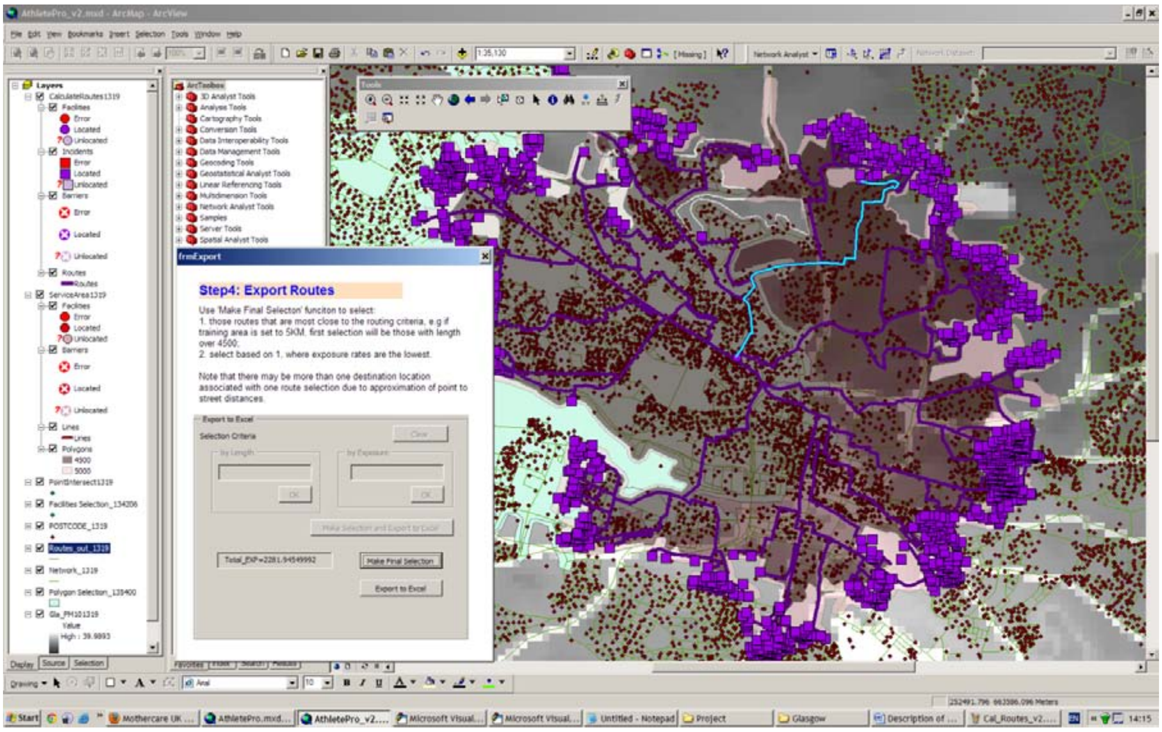

Figure 10. Export the training route to Excel

Part II: Obtaining exposure analysis along pre-defined routes

As with starting the analysis in the first option, the user firstly needs to load the project folder (as shown in Figure 1) then at the "switch board", select the second option 'load your routes, extract exposures' (Figure 11).

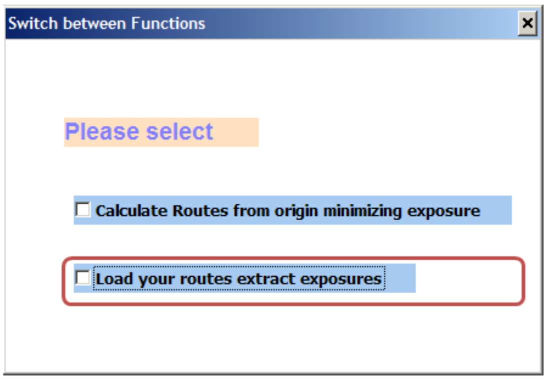

Figure 11. Switch to extracting exposure for routes option

Step1:
The first step for extracting air exposure value for pre-defined routes requires the user to load in the air concentration surface. An example of Glasgow average PM_{10} concentration surface for 2001 (as described above) can be found inP ROJECTPATH\Project\Default_Concentration\. The user must select from the listed name for the chosen air pollution surface in the list box then press 'load' function to use the concentration data (Figure 12).

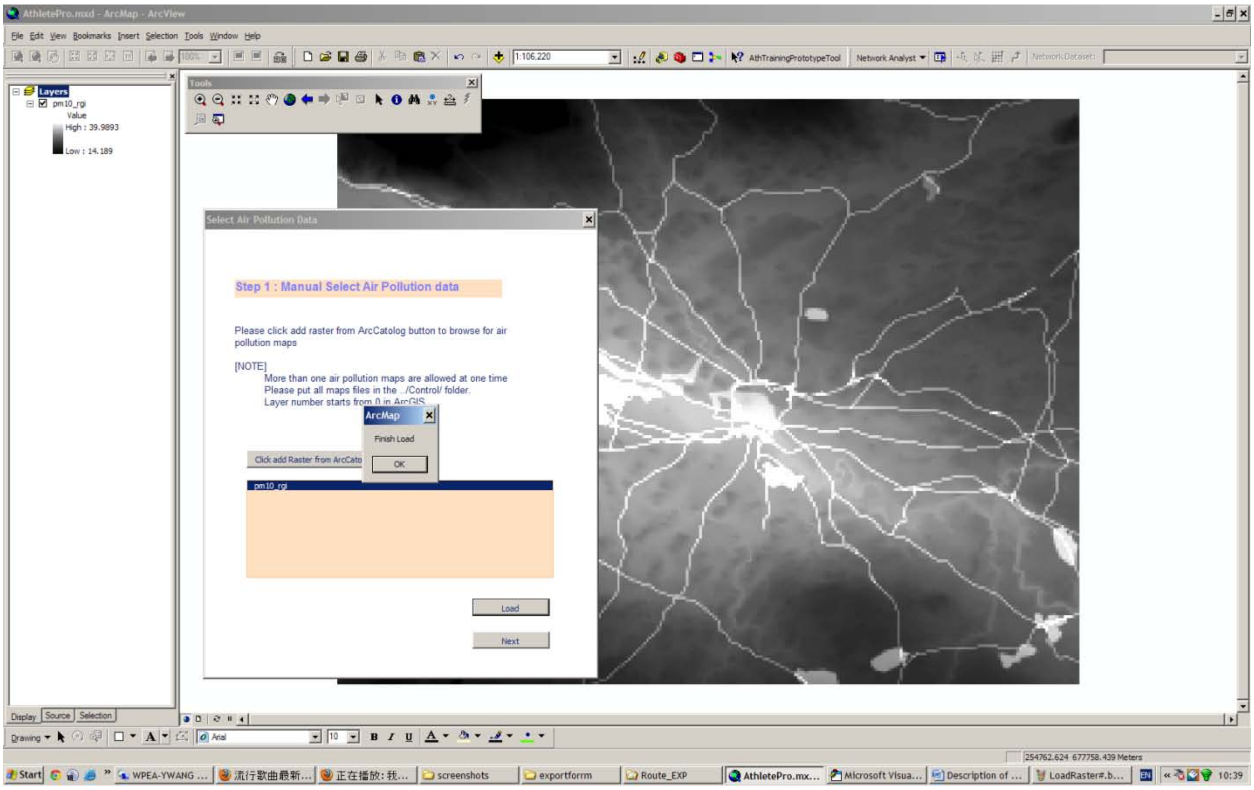

Figure 12. Load air concentration data (Glasgow PM10 example)

Step2:

To extract exposure scores, this stage follows the same set of procedures as described in part 1, but this time for a single route or small number of routes rather than generating new routes from the whole network. Figure 13 shows a series of routes loaded into the software for consideration.

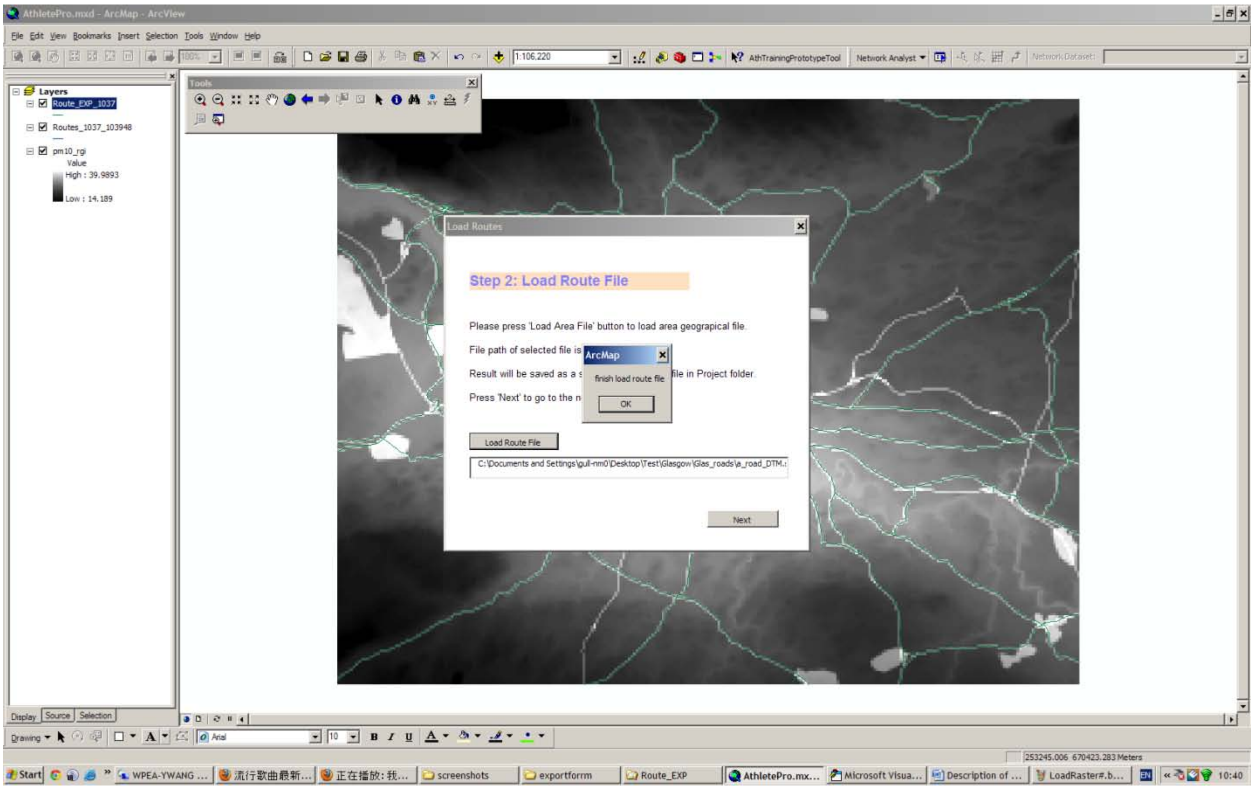

Figure 13. Load pre-planned routes

Step3:

Similar to Part 1, the tool breaks each loaded route into point features according to the resolution of the air pollution surface. There is an option to override the default resolution and to create a finer series of points, which is sometime preferable where the underlying air pollution surface is coarse relative to the road network. Figure 14 illustrates the segmentation of the routes corresponding to user input of 100m points.

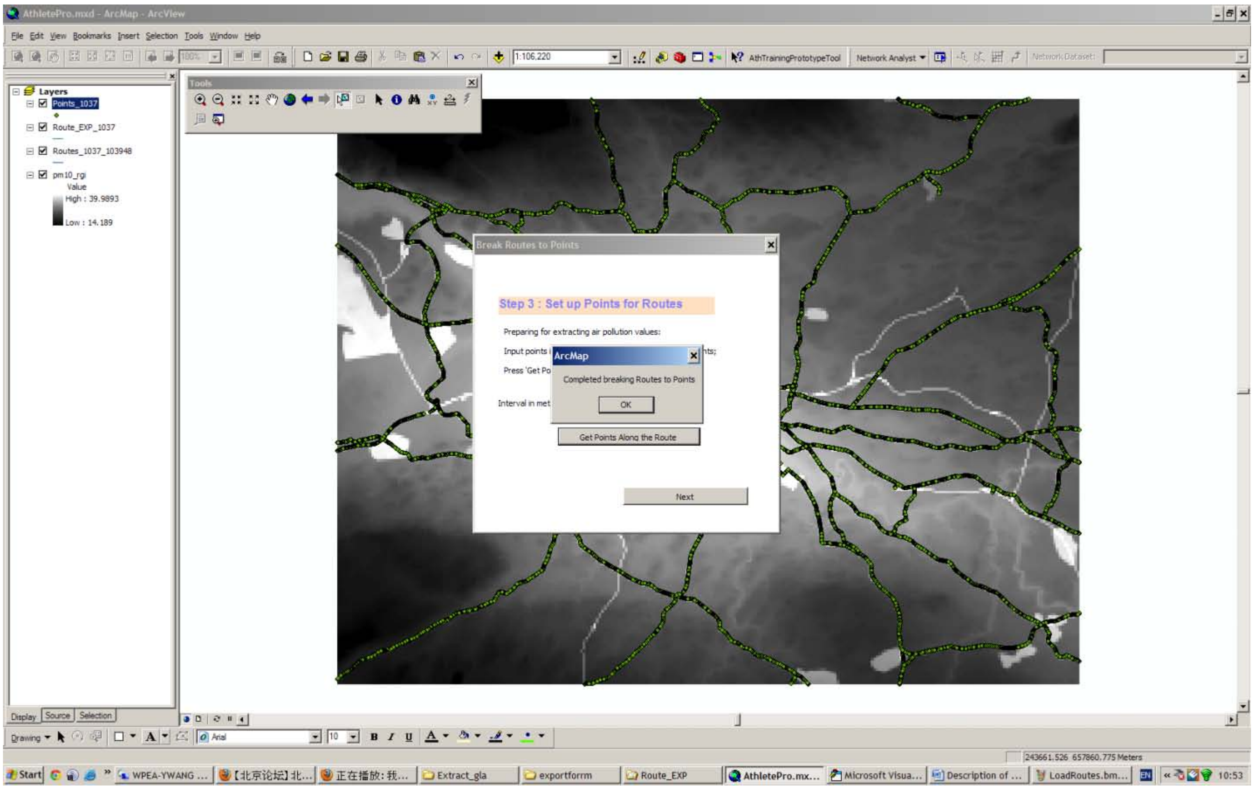

Figure 14. Break routes into points according to user input interval

Step4: Extract exposure values for routes

This step will take the points created along the routes and intersect them with the air pollution surface to extract an exposure score for each point. After each point gets a value of PM_{10}, exposures are averaged along individual routes using routeID (Figure 15).

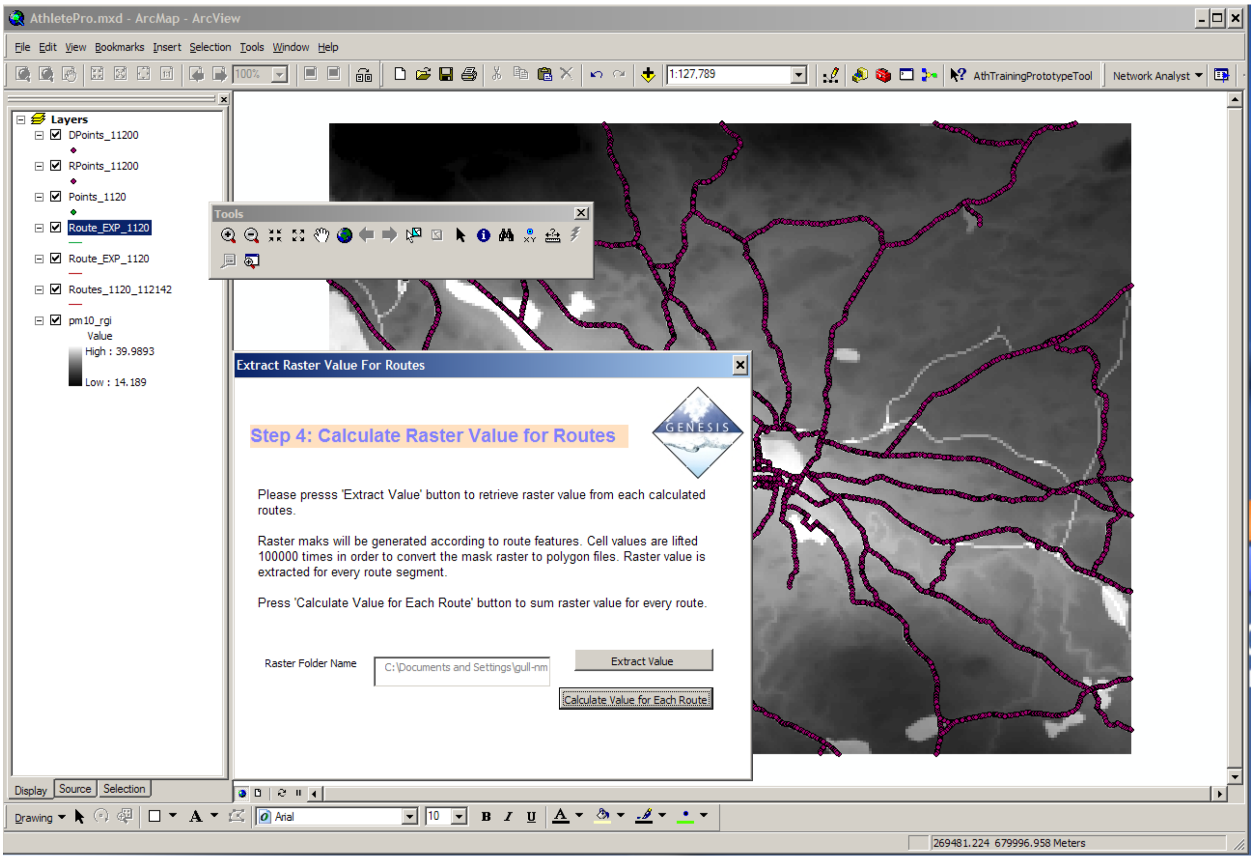

Figure 15. Extract exposure value for routes

Step 5: Select one or more routes

The result of step 4 is a new route feature class, which has all the original route features along with newly extracted exposure scores. Routes with the lowest average exposures are identified using the 'Make Final Selection' function and the user has the option to export results to an external Excel file as shown in Figure 16 and Figure 17.

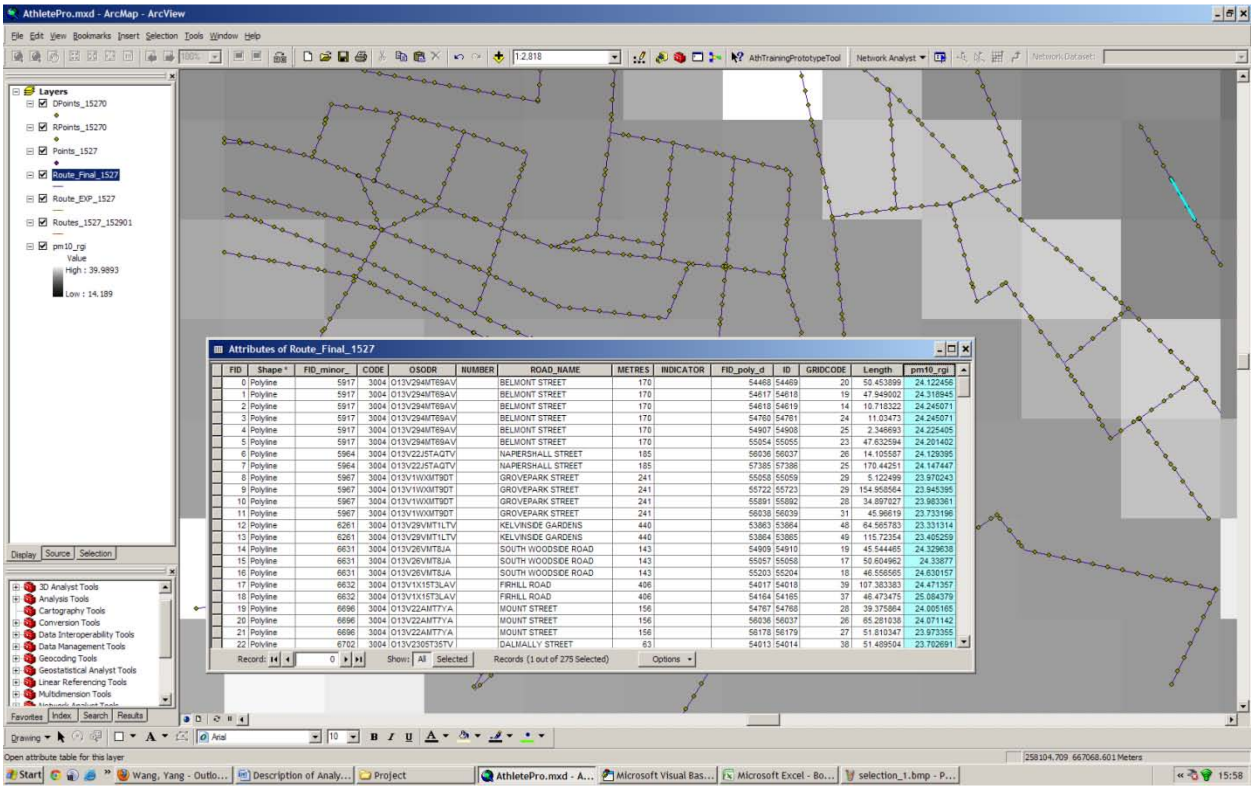

Figure 16. Final results of routes exposures

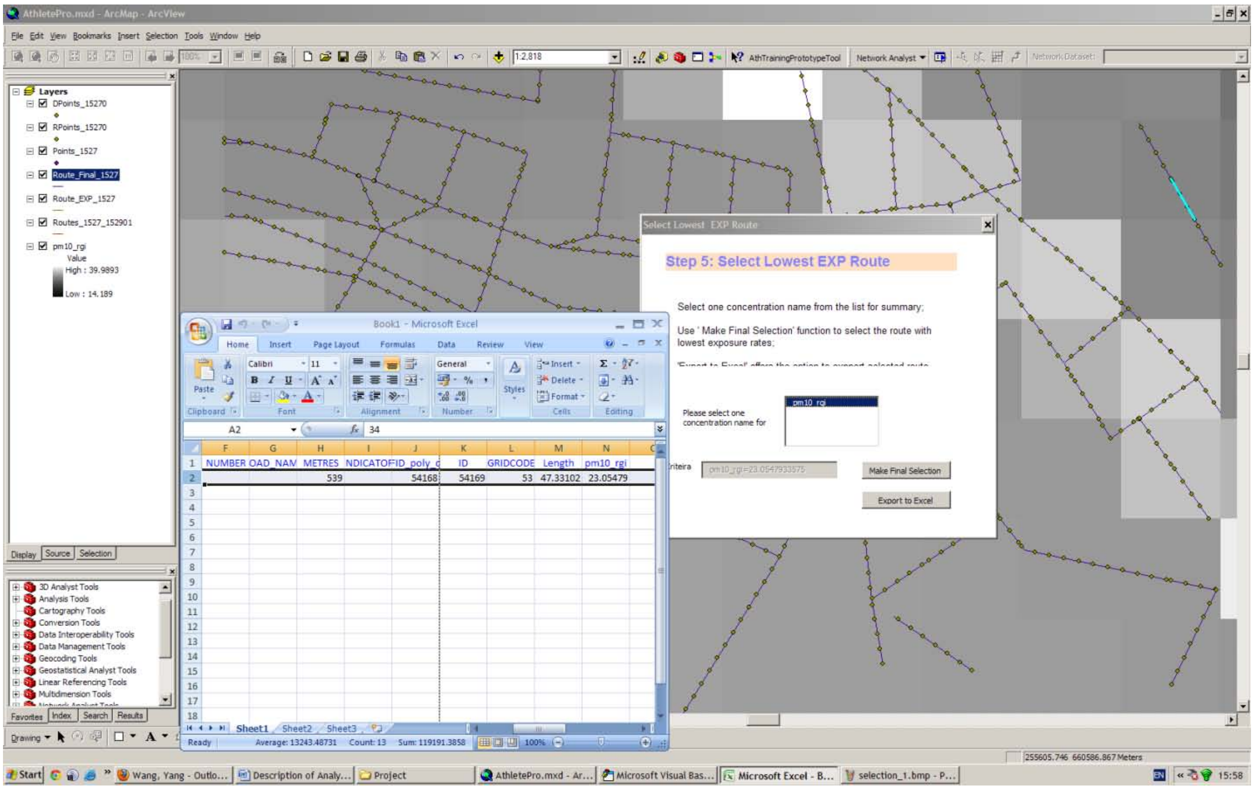

Figure 17. Selecting route with the lowest exposure rates

Future developments

The prototype could undergo a number of revisions as part of future development. The main revision would be to programme the software in open-source GIS so that it can be run on any machine as freeware. Some improvements to the user interface are envisaged as part of this process.

Three main revisions would be:

1) The implementation of the digital terrain model in route selection to allow for differential ventilation rates to be applied with respect to gradients along routes.
2) Development of algorithms to search for "looped routes" and "way points" as the current system only uses an "out and back" approach.
3) The current approach uses raw exposure scores but we intend to implement a categorical scale (e.g. 1 lowest to 5 highest) for rating the exposures along routes before any general release of the software.

We are using a coarse national air pollution model for 2001 based on land-use regression techniques. Ideally we would be able to develop air pollution modelling capacity in collaboration with local authorities to provide higher resolution air pollution surfaces for the Glasgow area. We developed a good relationship with the Glasgow local authority and Strathclyde Passenger Transport, both of whom were keen to work with us to develop air pollution modelling capabilities for the Greater Glasgow area. However, this was not feasible within the lifetime of this pilot study. Air pollution modelling would provide not only higher resolution (i.e. higher precision) air pollution surfaces but also models of emissions of primary particulates which relate much better to the black carbon measurements than the coarse, total PM_{10} model that we used; thus we were not able to compare modelled exposure with data on black carbon exposures collected on the same routes. The modelled exposures presented here are for demonstration purposes only and relate only to roads (we also would ideally include other transport routes in the exposure assessment such as footpaths and towpaths that do not follow the road network). Nonetheless, with improvements in air pollution modelling we would be able to evaluate the modelled air pollution exposures. This would have two distinct advantages over the work that we have been able to conduct:

1. It would allow us to perform a full and thorough evaluation of the model, with additional ambulatory monitoring, and produce the results from evaluation for publication in the open scientific literature
2. Following validation of the model we would be able to quantify a more realistic exposure burden of athletes training in different parts of Greater Glasgow and provide information for event route planners (e.g. Commonwealth Games)

In saying this we assume that there would be health benefits to athletes' from choosing routes with reduced exposures to primary air pollution. This is investigated in the next section based on limited exposure and performance data collected in this study.

Recruitment and Collection of athlete's air quality exposure and performance data

Participants and training sessions:

Members of the Garscube Harriers (http://www.garscubeharriers.org.uk/index_en.php?pageid=home) running club were recruited through an organising committee liaison contact: Mr Robert Cuthbertson. A total of 6 sessions were assessed for air quality (i.e. black carbon) during the period February to April 2012 and 5 for full runner performance. Route data and raw monitoring results are shown in the Appendices and summarised below. Training plans were adjusted to accommodate investigator's priority to contrast urban/rural environments, but were constrained by training schedules and local situation to ensure participants were afforded appropriate health and safety conditions (particularly guarding against running in isolated environments). Training sessions were completed between 7pm and 8pm on the days indicated below with biometric data collected from recruits before and after each session. Sessions started from the Garscube Sports Complex, Maryhill Road, Glasgow. A total of 23 adult participants, mean age 46.7 years, were recruited (11 x F; 12 x M). The average number of years of training for all participants was 11.8 years. Average mileage per week run was 24.7 miles. Seventy percent reported participating in competitive running. Seven subjects completed all runs and had complete data sets and were included in initial assessment.

Data on biometric parameters – summary, significance

The present project compared the blood oxygen saturation and peak expiratory flow as potential indicators of the effects of air quality on physiological factors affecting running performance. Statistical evaluation of the data for the seven subjects completing the entire study produced interesting data. It was uniformly seen that peak ventilator flow decreased between the pre- and post-run measures with a mean reduction of -53.5 mL/s (SD ± 21.5) across all five measured runs (see Figure 18). The magnitude of change was only significant for the final two runs ($p = 0.01$ and 0.03 respectively). Blood oxygen saturations were not statistically altered over the five runs but trends in the limited observations may be apparent and have been included in Figure 18.

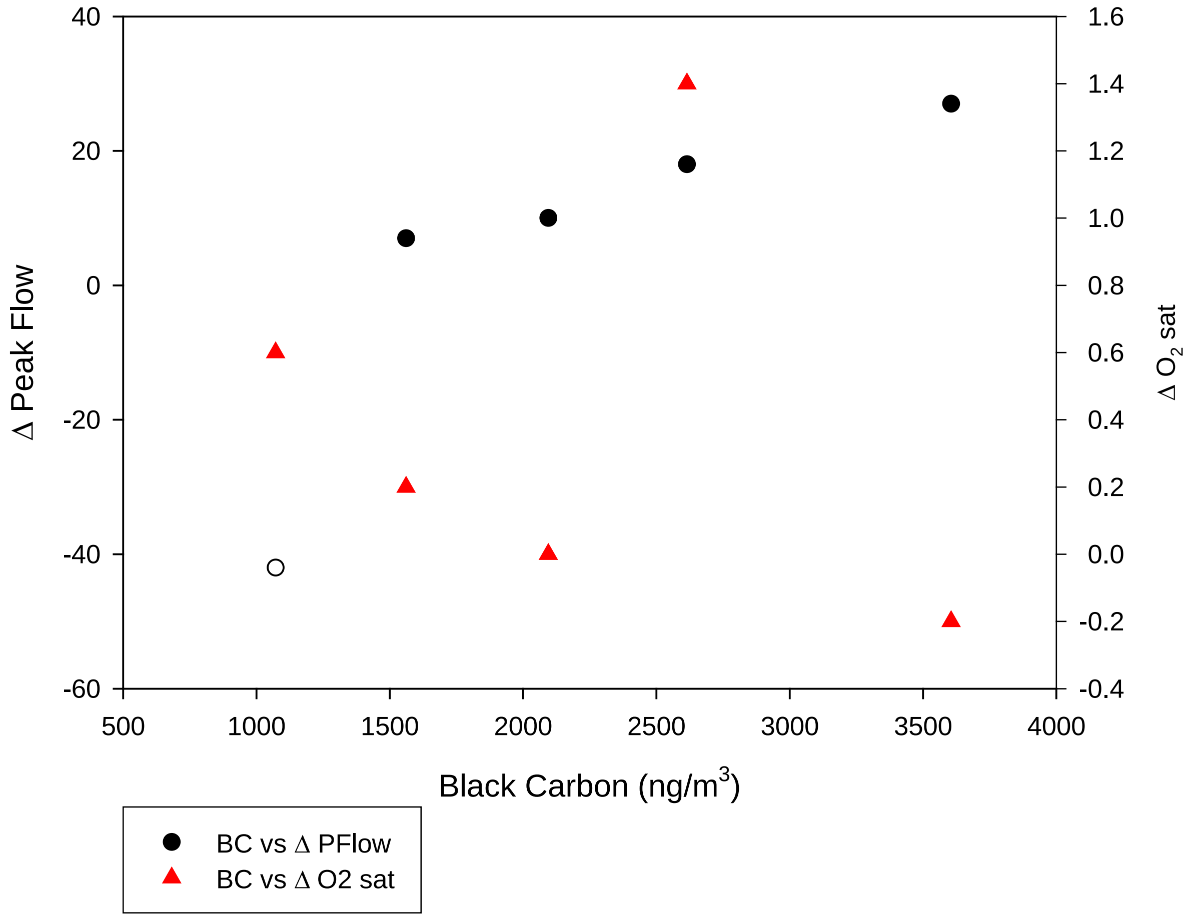

Figure 18: Change in peak expired ventilator flow (ΔmL/s) and O_2 saturation after a training run versus average black carbon exposure (mean exposure for each run and mean of n=5 full run participants).

Air Quality from Black Carbon Measurements – summary, significance

Data summarising exposure levels is presented in Table 1. This shows compilations for the six runs monitored during training sessions and is visually presented in Figure 19.

Table 1: Summary of average Black Carbon exposure data for a range of exposure conditions (Glasgow and environs: February-April 2012)

a. Training Sessions

Black Carbon exposure ng/m^3	Session 1: 16th Feb. 2012	Session 2: 23rd Feb. 2012	Session 3: 1st Mar. 2012	Session 4: 29th Mar. 2012	Session 5: 5th Apr. 2012	Session 6: 12th Apr. 2012
Mean	1,832	1,072	3,605	2,095	1,561	2,615
Sd	1,124	1,013	1,804	1,393	1,359	2,021
Max	4,940	7,442	8,362	6,562	6,058	8,577
Min	105	6	244	51	49	86
Exposure time (min)	62	79	76	54	59	57

b. Training Session 3: 1st March 2012 circuit (Anniesland Cross) followed multiple times, additional run along Great Western Road (GWR) and "return" (Anniesland Cross - to Garscube) using bicycle.

Black Carbon exposure ng/m^3	13:00	14:20	15:11	16:00	17:20-17:45
	circuit 1	GWR	circuit 2	circuit 3	return
mean	1,972	2,060	3,327	4,434	5,135
Sd	1,325	1,764	3,001	2,776	2,198
max	6,674	10,521	13,182	12,629	8,755
Min	681	480	945	1,428	1,255
Exposure time (min)	36	53	26	34	21

c. Road level exposure during car commute between East Kilbride (G74 4TR) and Paisley (PA1 2BE)

Black Carbon exposure ng/m^3	Pais-EK (6th February 2012)	EK-Pais (8th February 2012)	Pais-EK (7th February 2012)
	17:00	06:00	17:00
mean	9,236	2,797	7,782
Sd	3,464	852	3,140
max	21,653	4,709	15,934
Min	4,824	1,514	1,775
Exposure time (min)	48	23	37

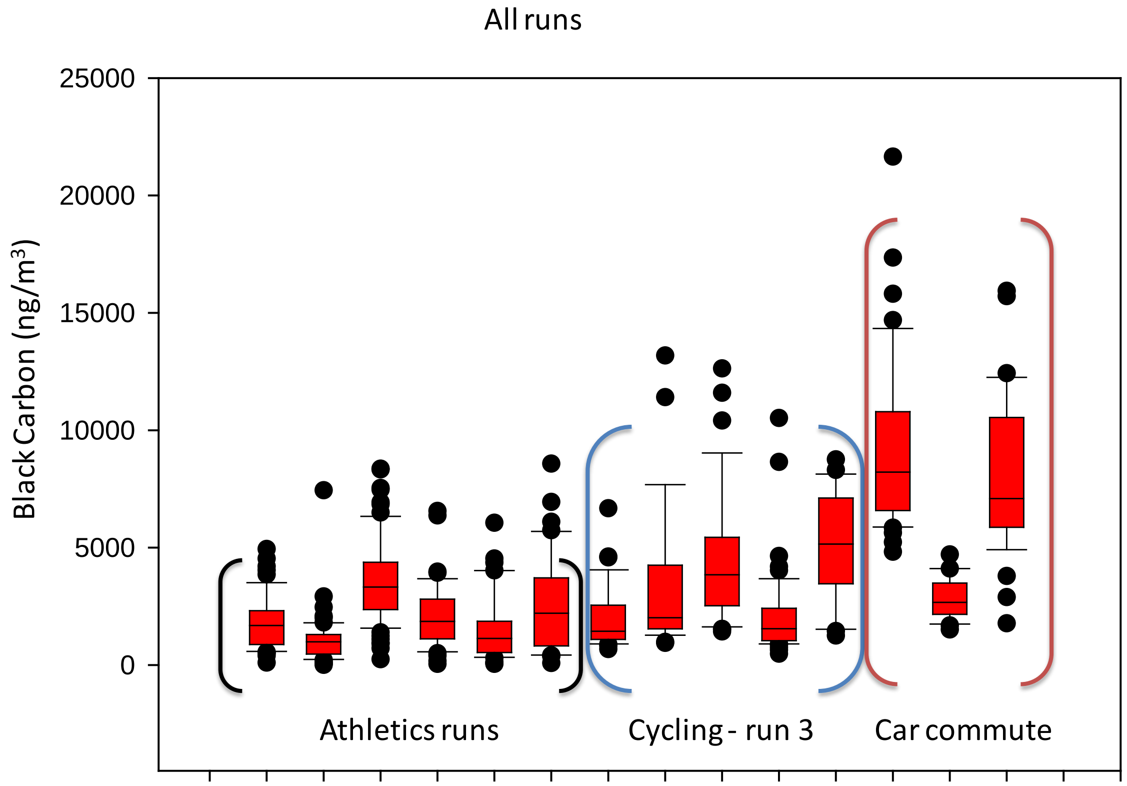

Figure 19: Boxplot summary of Black Carbon exposure for different collection periods.

The relative differences between each exposure condition (training, cycling and car commute) emphasise the variability across environments. In relation to training sessions no strong difference between "road" and "country" sessions is obvious from the plots and in road v pavement exposure, rush hour v off peak travel exposure highlights the strong variability. The third training run (1st March 2012) shows the most significant increase in exposure. This date includes a monitoring run using a cyclist along the circuit earlier in the day. Data are summarised in the plot below (Figure 20), which emphasises that the pre-training exposure through afternoon into rush hour was higher, reflecting influence from traffic levels.

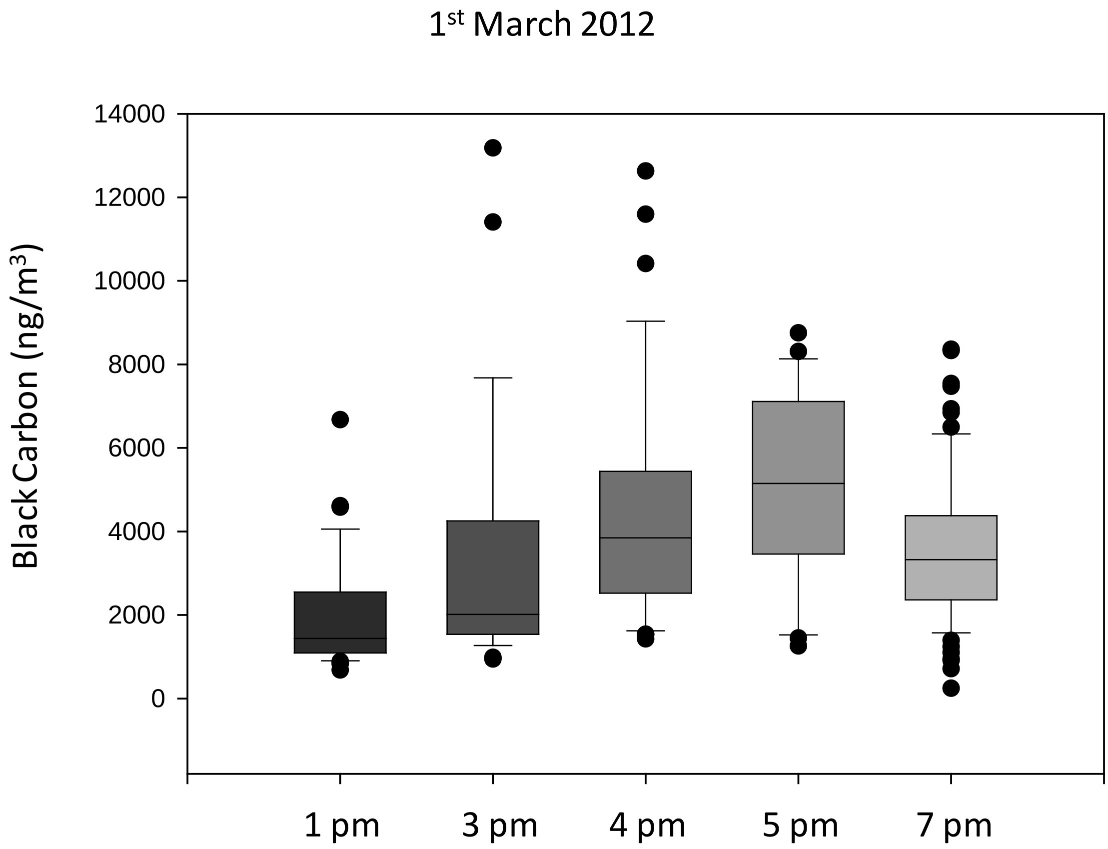

Figure 20: Boxplot summary of temporal exposure to Black Carbon for training circuit (session 3) Anniesland Cross/Crow Road/Garscube.

This emphasises variability and the relatively rapid decay in levels into the evening training period. The elevated exposure levels on this date compared to other training sessions may relate to wider air quality episode. The PM_{10} levels from closest air quality monitoring network site (Broomhill) for three days straddling 1st March 2012 is shown in Figure 21. Black carbon is a constituent of PM_{10} which is variably correlated (in space and time) with PM_{10} dependent on the proportion of primary and secondary particles forming the total (PM_{10}).The 1st of March shows higher PM_{10} levels from preceding day, which may reflect response seen in the Black Carbon data.

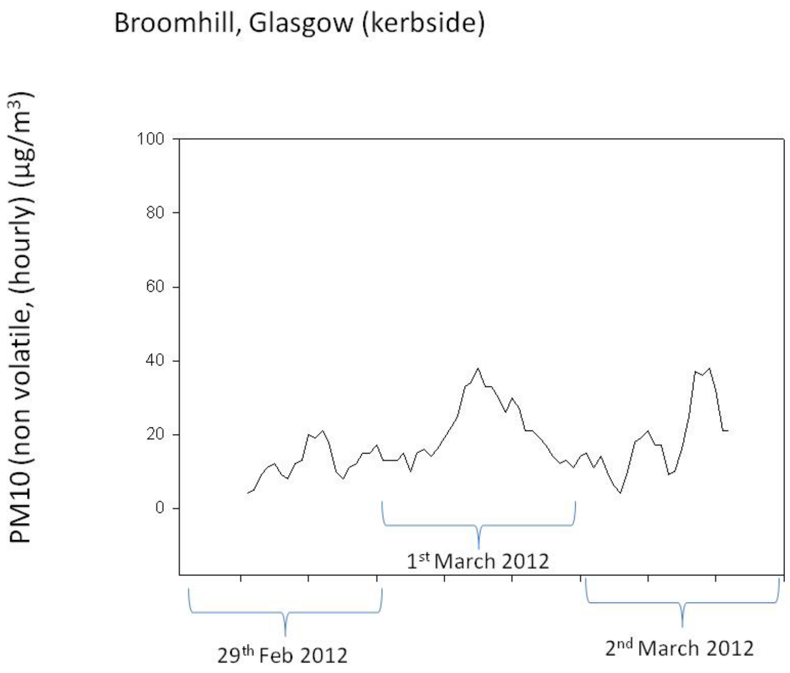

Figure 21: Hourly PM10 Broomhill, Glasgow (kerbside) Air Quality Monitoring Network Data for the 3 day period 29th February – 2nd March 2012.

Conclusions & Further work

The collection of combined athlete performance and black carbon exposure data has been successfully piloted a number of protocol issues noted by the team in recruiting and sustaining participation, and a methodology has been established for further work.

The results of the performance study do not provide statistically significant or robust conclusions from the work, but trends in the basic performance data and air quality (illustrated by BC values) are suggested from the limited number of complete participant data sets. The air quality encountered during the training runs are likely to include lower levels of exposure at the locations used as we necessarily (to fit in with the running club schedule) undertook the fieldwork in a suburban setting during evening periods. However, the car commute showed higher order of magnitude in exposures (e.g. two-to-three fold) which may be encountered by athletes in the Greater Glasgow are. Future work should also look at higher exposure locations given the results presented here. Follow up work on the relation between performance and air quality needs to consider:

1. Recruitment issues – a number of cohorts from different locations, initially ot target 30-40 complete data sets.
2. Split between male/female as well as adult/children participation.
3. Potential of other biomarkers from blood analysis
4. Spatial and temporal variability of environmental conditions such as temperature, and running conditions such as velocity;

The prototype GIS-decision support tool has been designed, developed and applied to the Glasgow context. This process identified a number of constraints on implementation and also priorities for development as noted above in the section on specific 'Future developments' for the air pollution exposure modelling.

Acknowledgements

Dr Julie Thomson, Innovation & Research Office, University of the West of Scotland, Paisley PA1 2BE
Mr Robert Cuthbertson and members of the Garscube Harriers

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Appendices:

a. Athlete data
b. Compiled route data

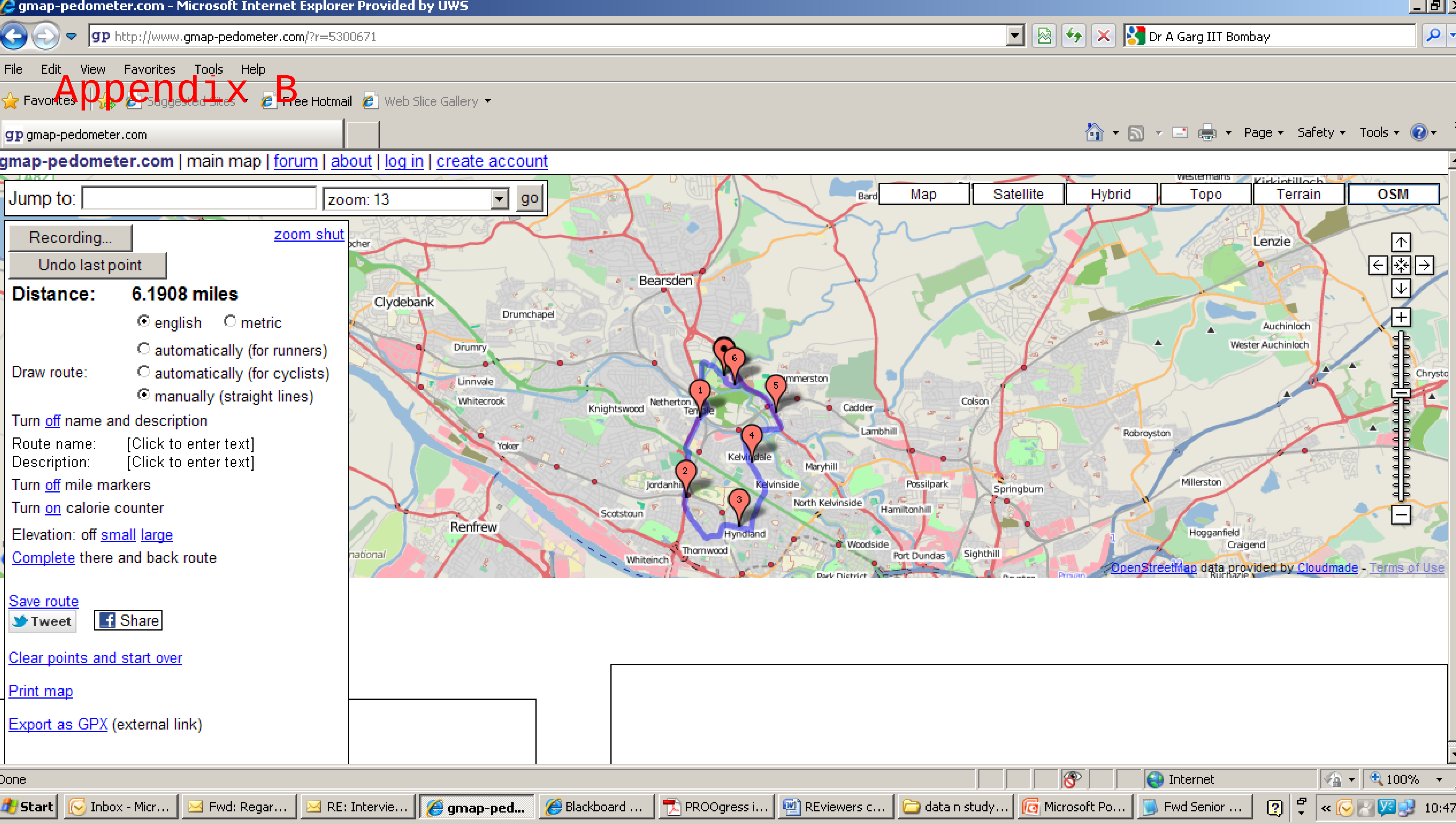
Appendix A

								Run 1	23-Feb-12					Run 2					
Subject	**Sex**	**Age**	**Ht**	**Wt**	**Yr Exp**	**Mile/Wk**	**Post Code**	**Pre HR**	**Post HR**	**Pre O2**	**Post O2**	**Pre PF**	**Post PF**	**Pre HR**	**Post HR**	**Pre O2**	**Post O2**	**Pre PF**	**Post PF**
1	f	47	1.6	48	4`	20	G131BP	51	111	97	99	425	410	122	144	98	97	430	425
2	m	60	1.77	70	30	30	G639EW	48	109	98	97	500	475	67	93	97	96	510	475
3	m	42	68	66	23	30	G20QW	53	106	97	97	675	700						
4	f	42	69	80	8	25	G639JD	73	102	98	98	475	475	70	127	98	98	450	450
5	f	47	1.52	48	24	25	G614RJ	80	123	98	96	400	425	70	130	97	98	400	400
6	m	63	66	57.5	7	40	G120FG	48	71	98	98	225	360	69	97	99	98	400	400
7	f	49	64	54	10	18	G432XZ	97	140	99	98	400	375						
8	m	35	1.88	94.5	10	10	G115AS												
9	f	42	64	55	5	24	G613BF	59	109	99	97	450	475	78	113	98	98	430	430
10	f	55	64	55	1.5	20	G612BN	74	110	99	99	450	450	83	159	99	97	450	450
11	f	38	1.65	60	3	15	G120NF	100	156	97	97	500	525						
12	m	40	70	70	2	27	G131DL	77	118	98	98	650	600	81	115	97	97	630	575
14	m	38	1.65	56	5	15	G613AH	59	142	92	97	600	650						
15	f	44	62	47	2	15	G315RP	76	113	99	98	525	500						
16	f	40	64	57	3	20	G521LG	73	122	98	97	525	510						
17	m	47	71	72	10	40	G156DT	48	83	98	96	500	500						
18	f	41	64	52	4	65	PA26JQ	39	80	99	98	525	500						
19	m	49	69	60	15	15	G614BN												
20	m	62	68	70	30	20	G149HY	64	104	96	97	400	550						
21	f	32	65	59	10	25	G627TH	62	114	99	98	400	410	81	133	98	98	410	375
22	m	54	69	72	25	15	G131SG	77	98	97	98	600	625	59	100	98	99	730	650
23	m	61	70	55	20	30	G200TY												
	Mean	46.7		61.7	11.8	24.7	**MEAN**	66.2	111.1	97.7	97.5	485.5	500.8	78.0	121.1	97.9	97.6	484.0	463.0
	SD	7.3		9.2	8.0	8.2	**SD**	13.8	14.6	1.1	0.7	78.4	68.9	11.0	17.5	0.5	0.7	83.6	62.2
							Paired t p value				0.68		0.21				0.34		0.05

Appendix A (cont)

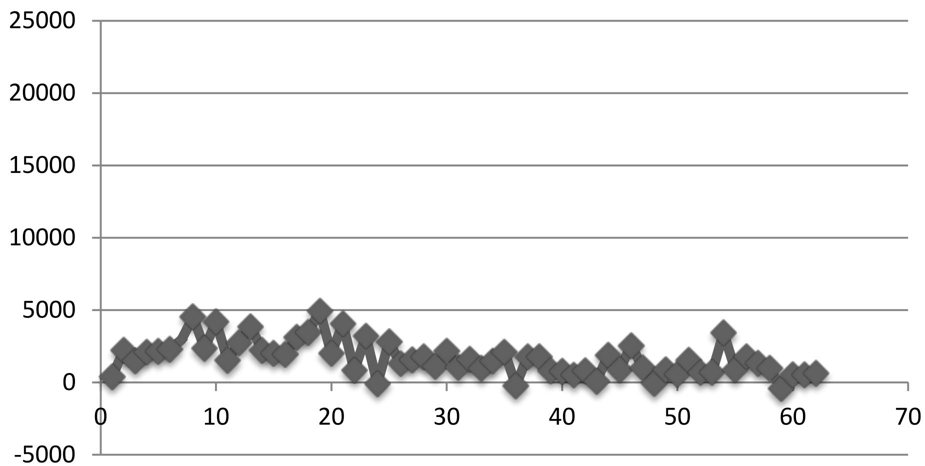
Run 3	01-Mar-12					Run 4	29-Mar-12					Run 5	05-Apr-12				
Pre HR	**Post HR**	**Pre O2**	**Post O2**	**Pre PF**	**Post PF**	**Pre HR**	**Post HR**	**Pre O2**	**Post O2**	**Pre PF**	**Post PF**	**Pre HR**	**Post HR**	**Pre O2**	**Post O2**	**Pre PF**	**Post PF**
78	124	99	99	450	450							106	128	99	98	430	420
55	99	97	97	650	660							51	86	97	96	670	650
72	112	97	97	475	460							77	128	97	98	460	450
82	137	98	98	400	400	76	133	98	97	410	400	66	130	98	98	400	390
55	87	98	99	450	300	48	77	98	98	310	330	80	140	98	98	450	410
72	112	99	98	375	350	85	141	98	97	375	350	75	126	98	98	380	360
						66	132	98	98	700	670						
65	130	99	98	450	450	55	121	98	99	440	420	101	138	99	97	460	450
						81	131	98	97	500	250	86	148	99	98	150	44
107	154	98	98	500	500							94	154	98	98	500	500
66	120	98	97	625	600	73	128	98	97	600	600	75	135	99	95	610	600
62	122	99	98	625	610	63	114	99	97	600	575	48	127	98	97	610	600
62	99	97	98	525	470												
43	94	99	98	525	500							46	88	98	98	520	480
67	92	99	98	500	510												
51	123	98	98	400	400	53	143	99	98	440	425	79		98		420	
62	105	97	98	525	650	56	87	99	99	700	675	49	91	98	97	670	650
61	106	98	96	550	540	49	72	99	98	570	560	55	137	99	97	560	550
66.3	113.5	98.1	97.8	501.6	490.6	64.1	116.3	98.4	97.7	513.2	477.7	72.5	125.4	98.2	97.4	486.0	468.1
10.1	14.4	0.7	0.5	64.3	80.6	11.0	20.9	0.5	0.7	109.8	125.7	16.0	15.9	0.5	0.7	98.4	107.6
			0.17		0.42				0.03		0.14				0.02		0.01

Appendix B

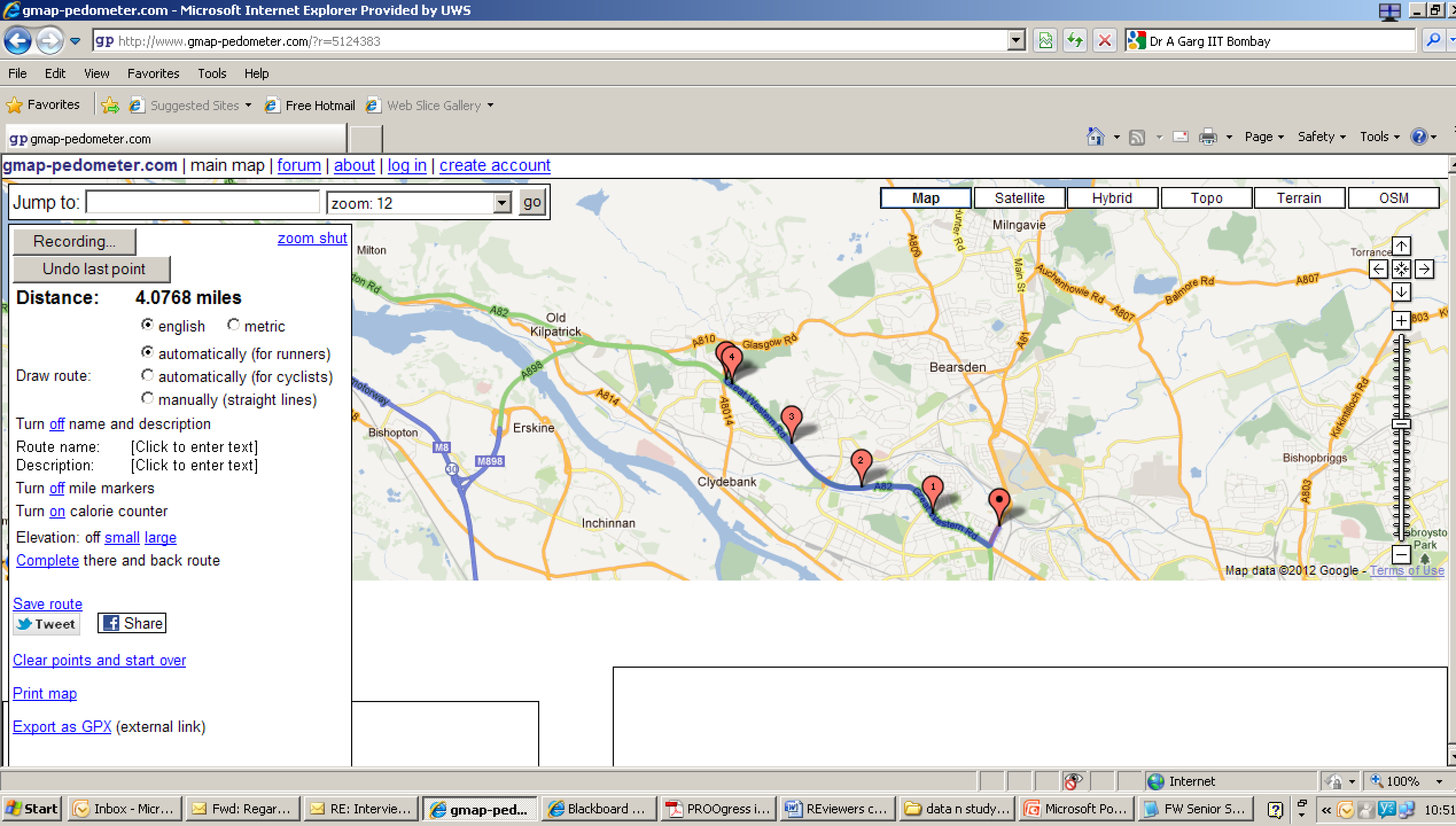


http://www.gmap-pedometer.com/?r=5300671

Run 1 = 16^{th} feb 2012



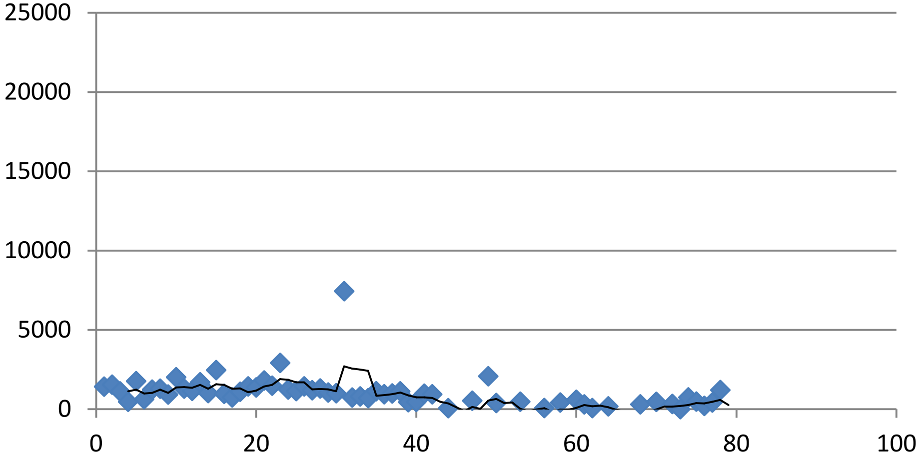
Run 1: 16th feb 2012 - road



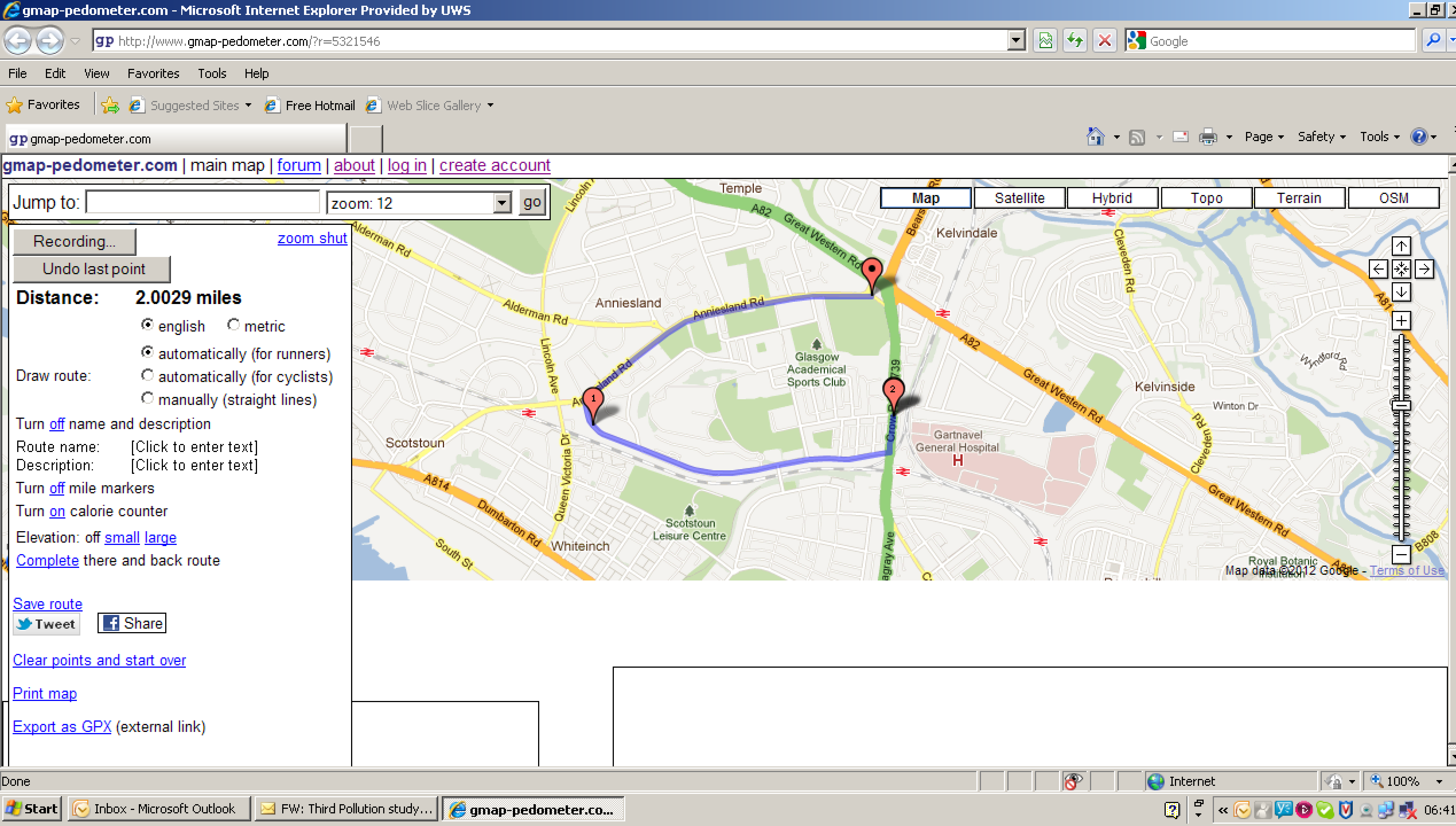
http://www.gmap-pedometer.com/?r=5124383

Run 2 = 23rd feb 2012

Run 2: 23rd feb 2012 - road

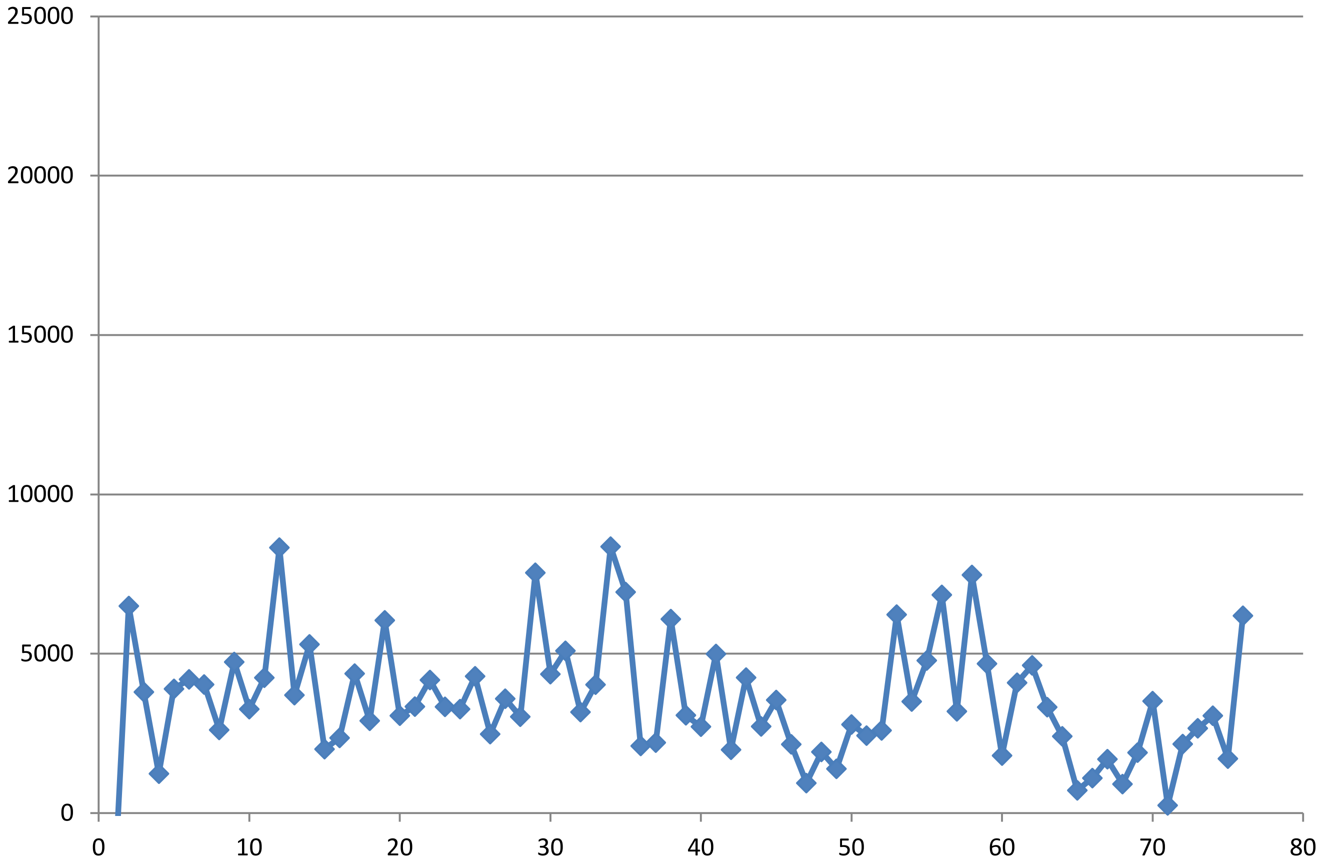


Windy!

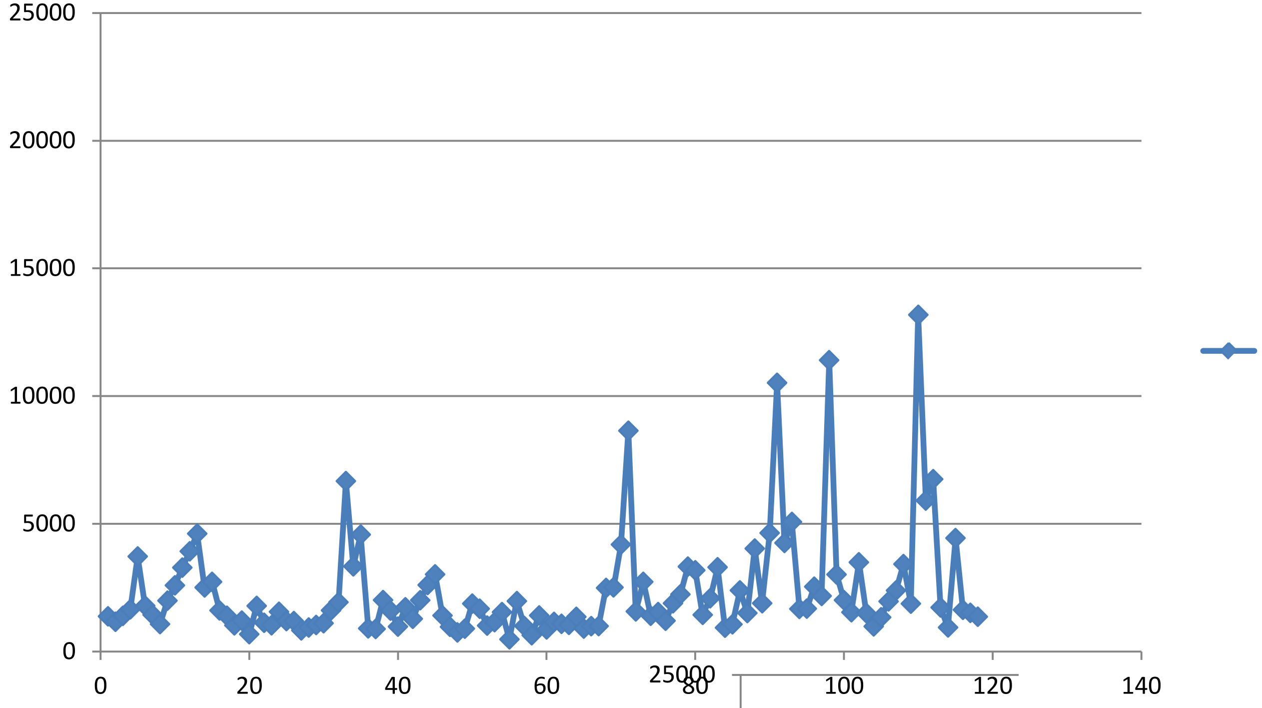


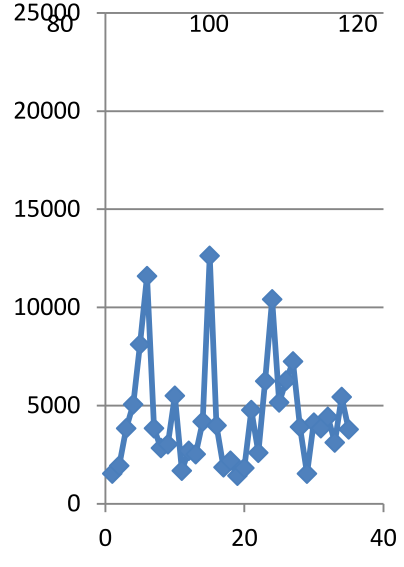
Run 3 = 1st march 2012

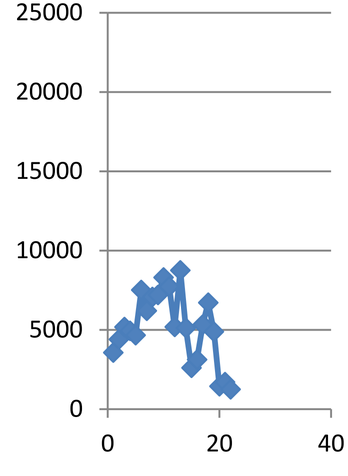
http://www.gmap-pedometer.com/?r=5321546



Run 3: 1st march 2012 (road run)

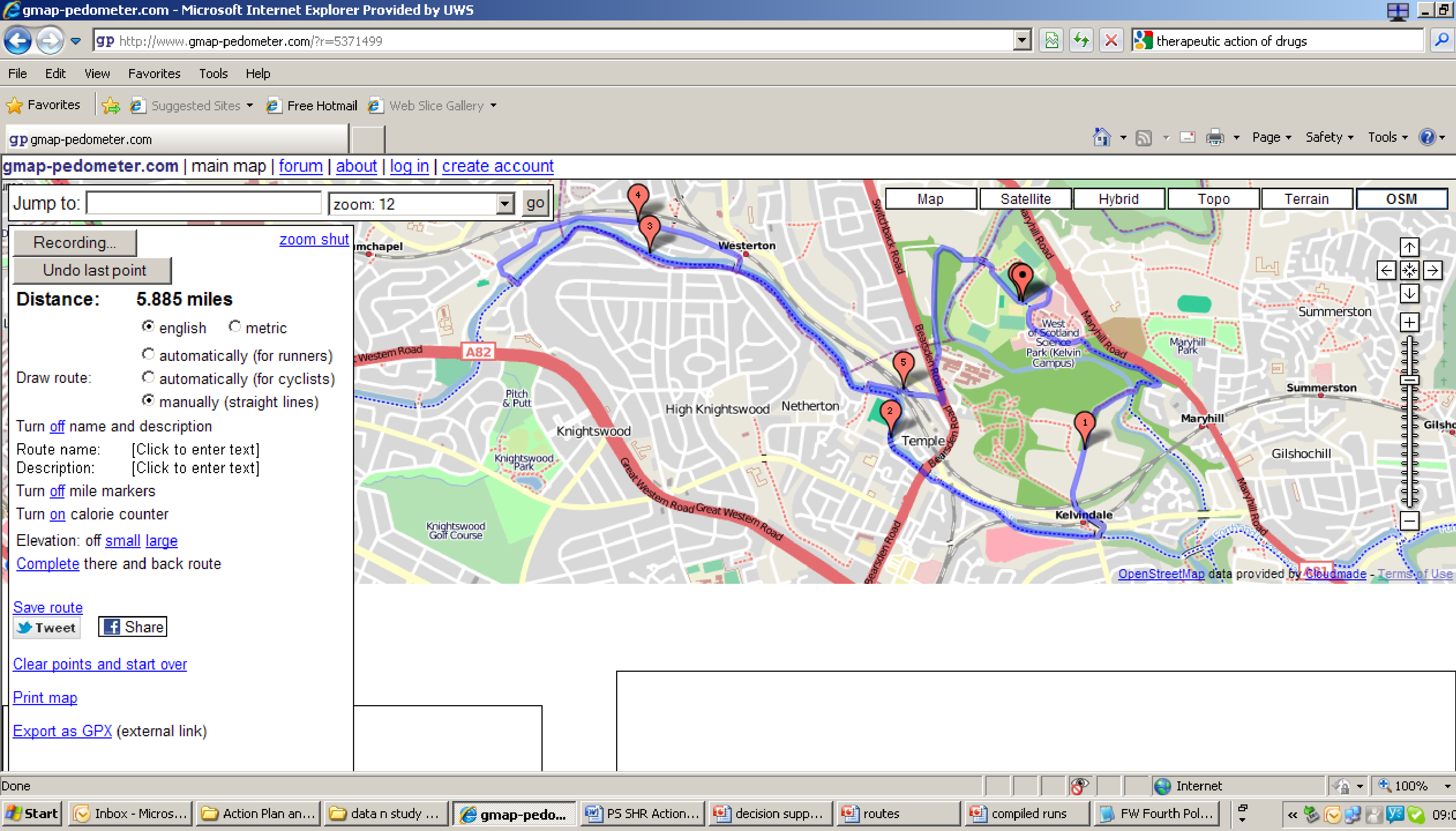






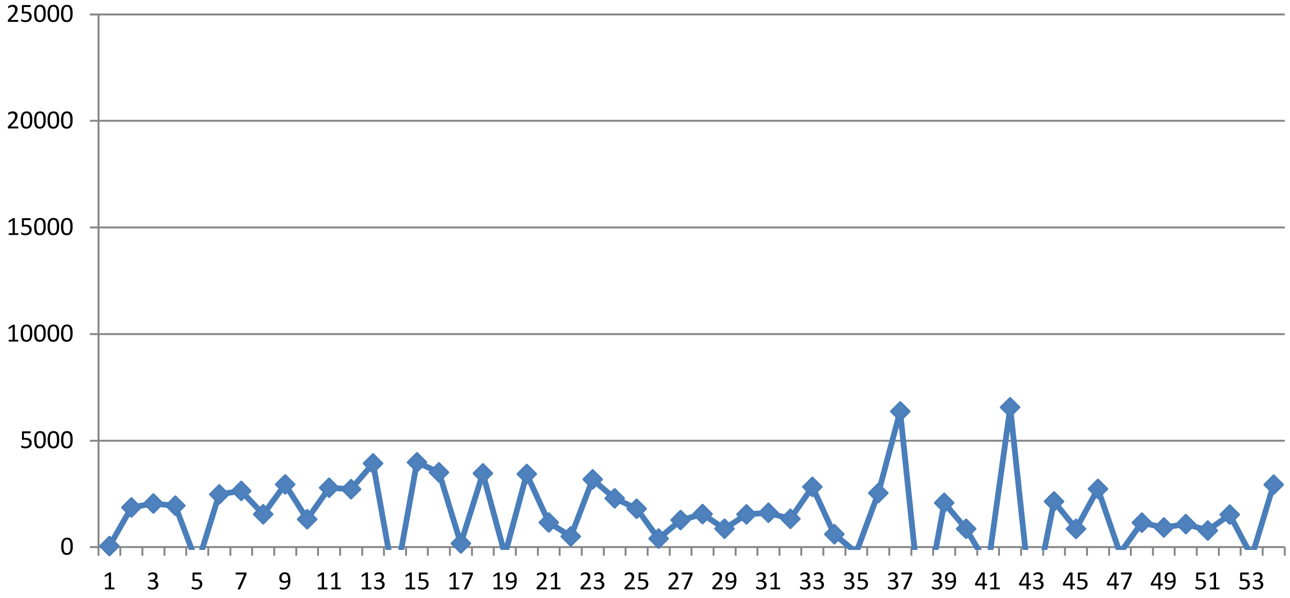
3

1st march 2012 – pre run

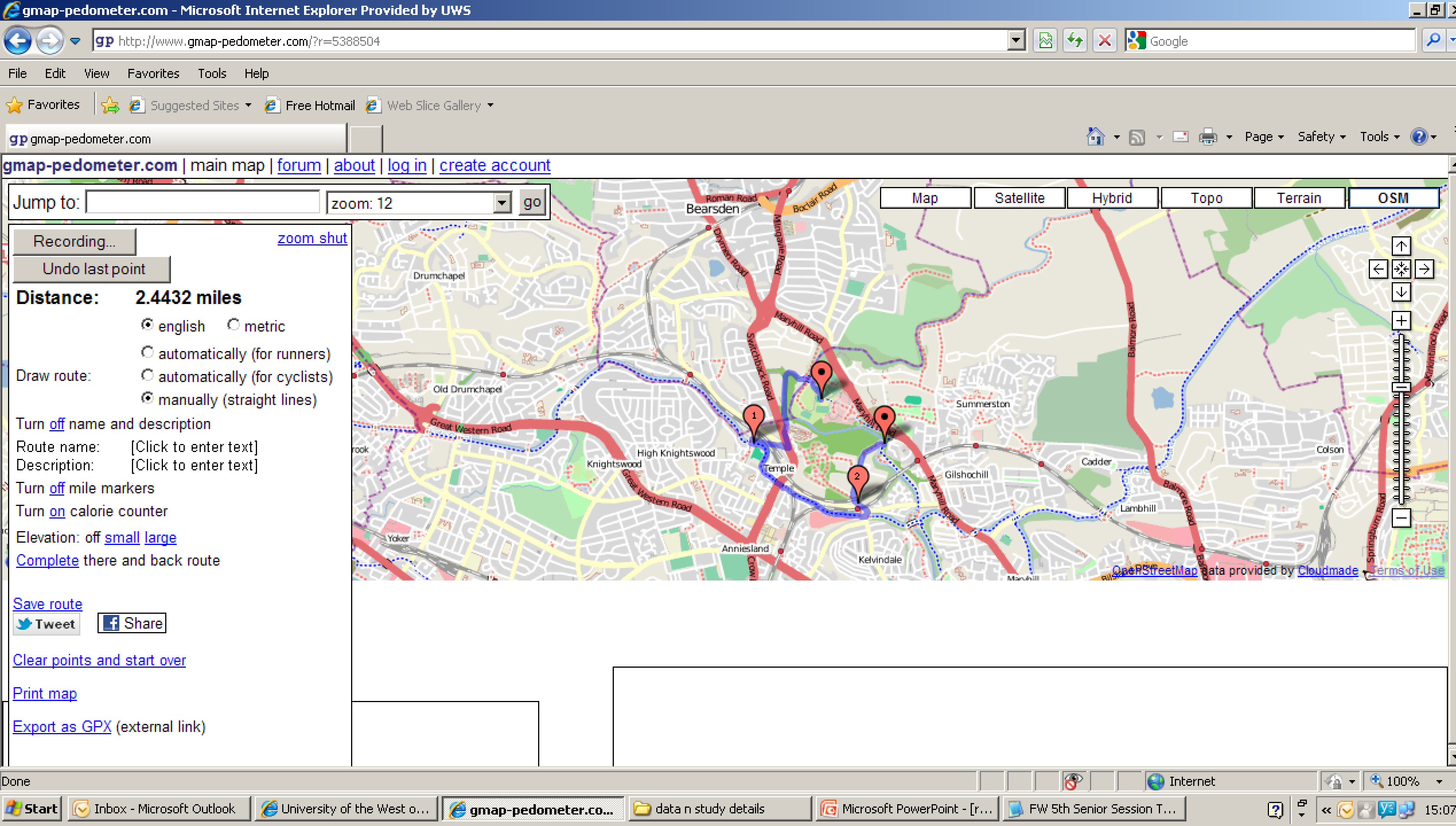


http://www.gmap-pedometer.com/?r=5371499

Run 4: 29th march 2012 - country



Run 4: 29th march 2012 - country

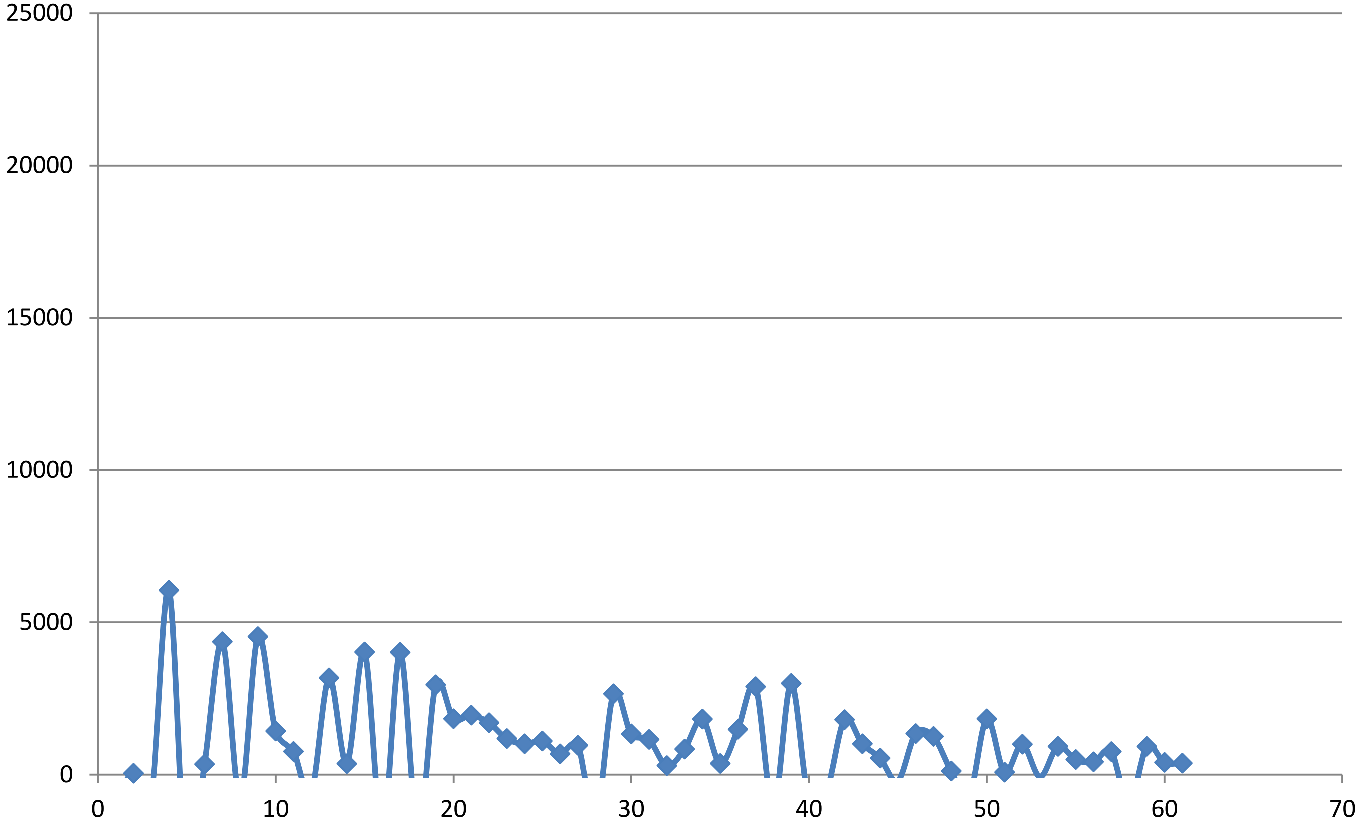


Warm up: http://www.gmap-pedometer.com/?r=5388504

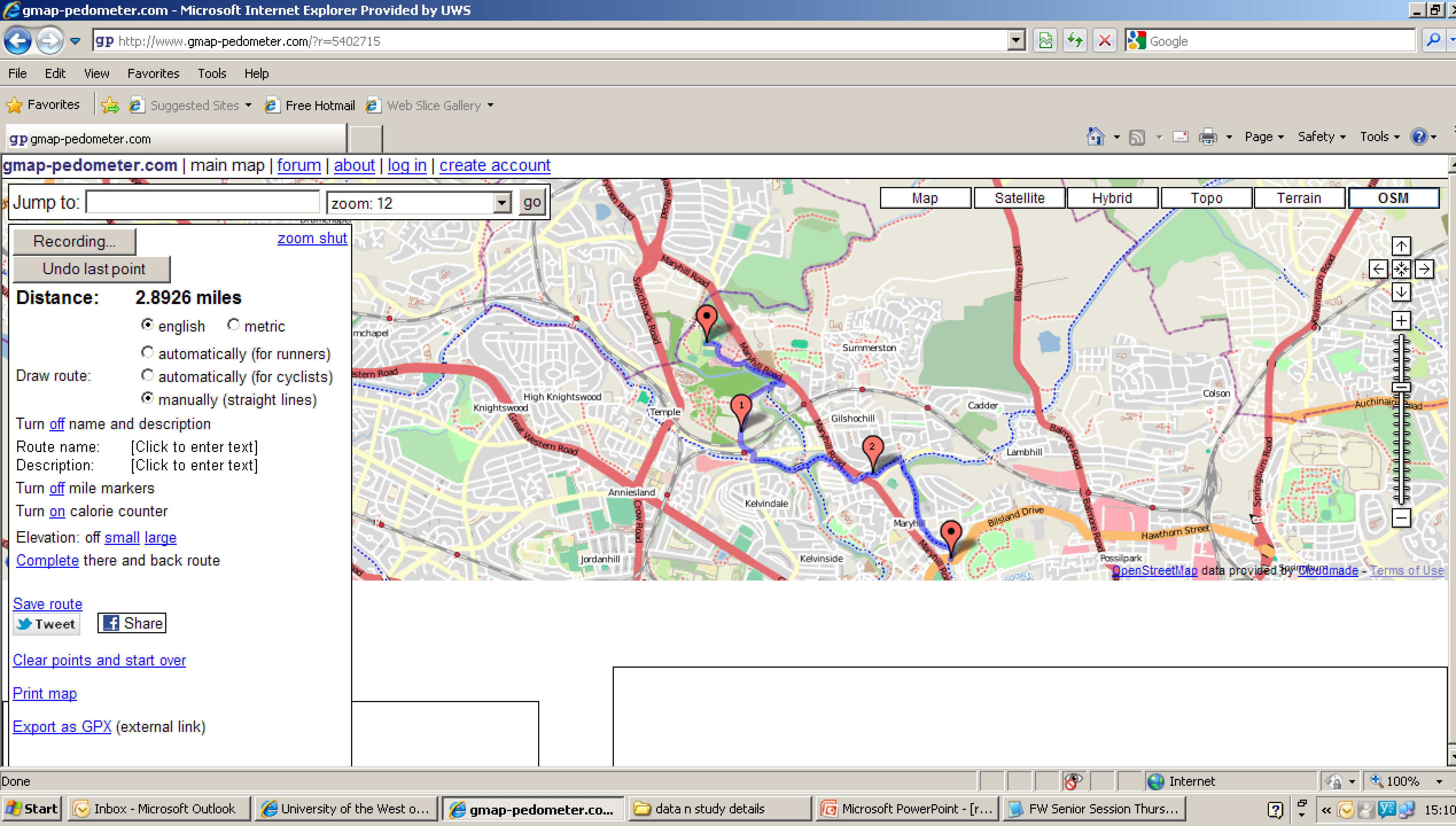
Tempo run: http://www.gmap-pedometer.com/?r=5388551

Warm down: http://www.gmap-pedometer.com/?r=5388536

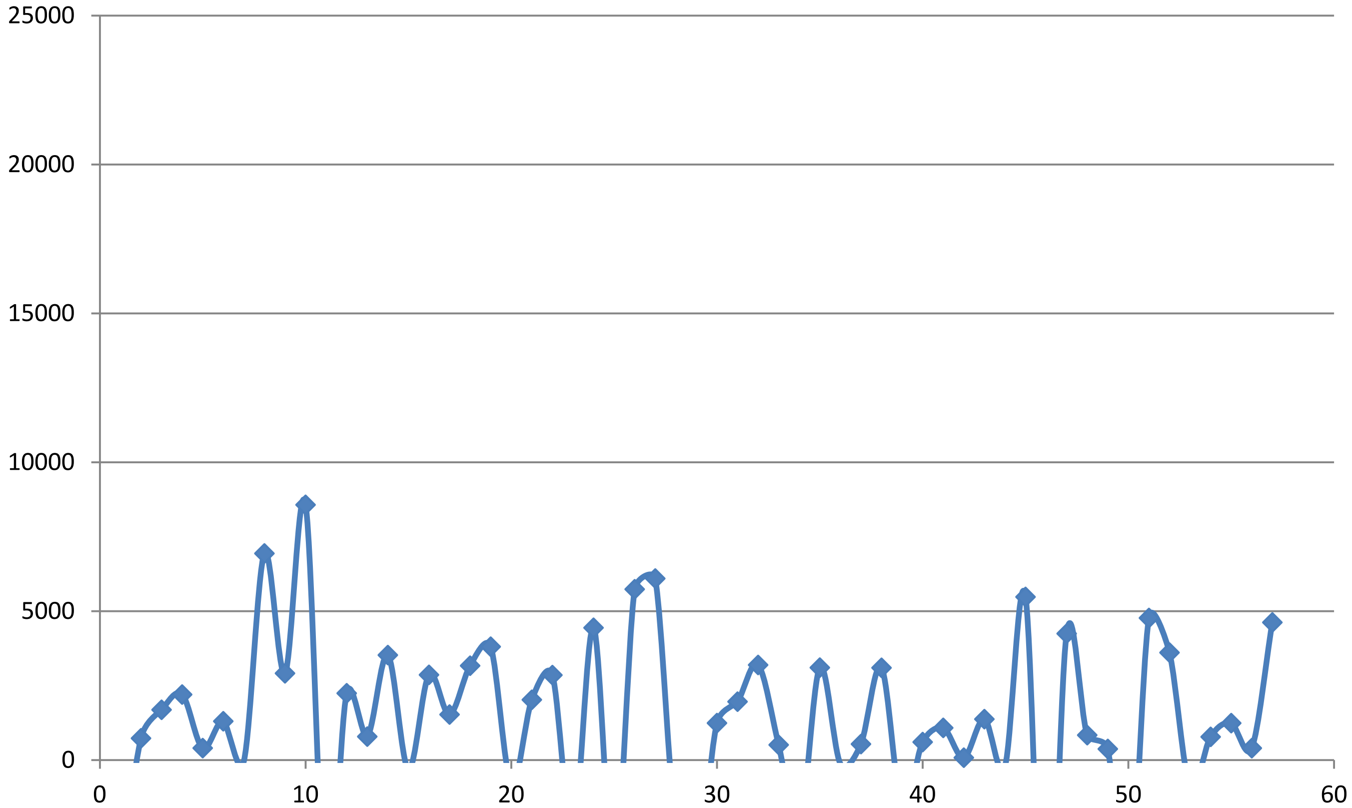
Run 5: 5th April 2012 country



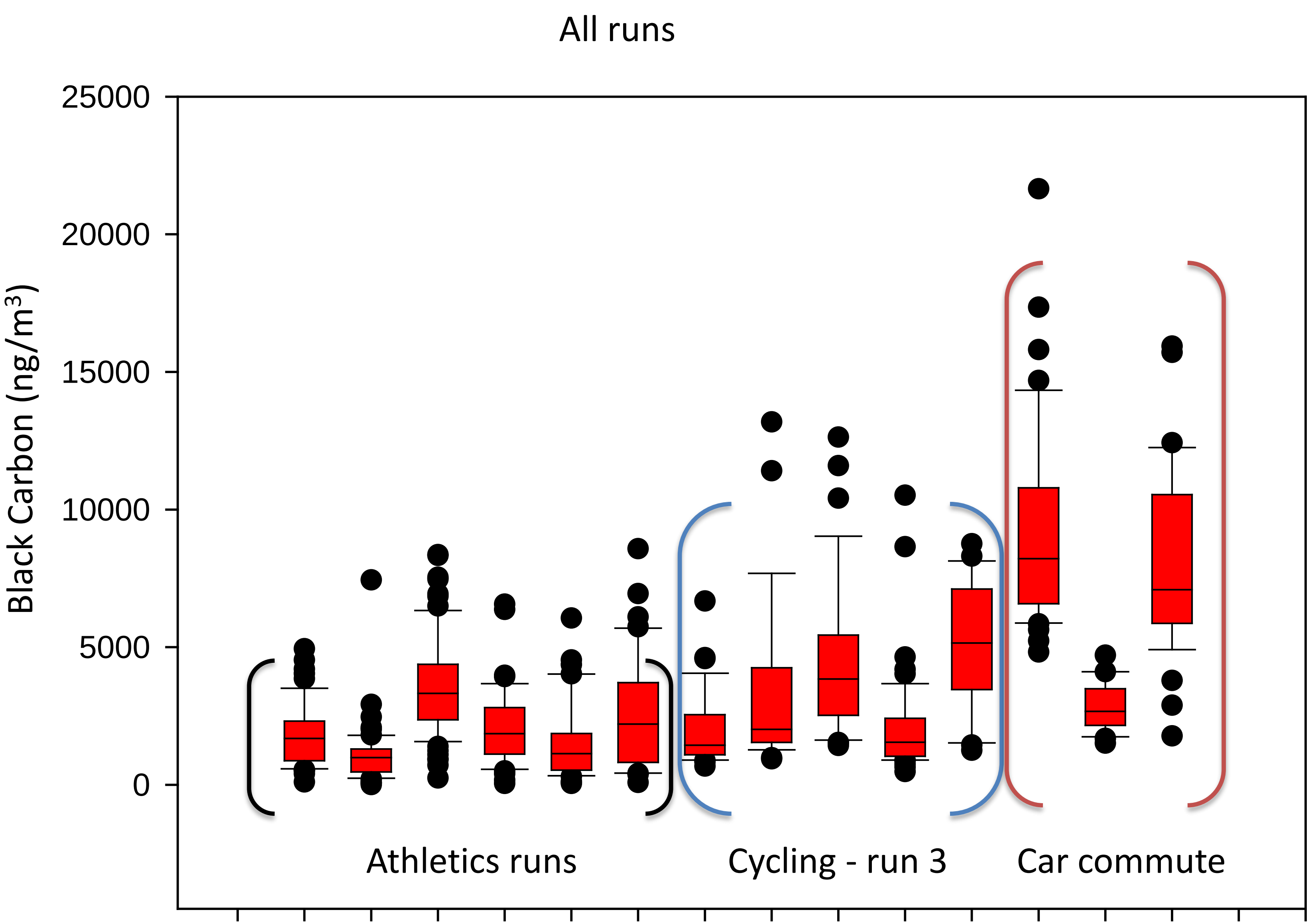
Run 5: 5th April 2012 country



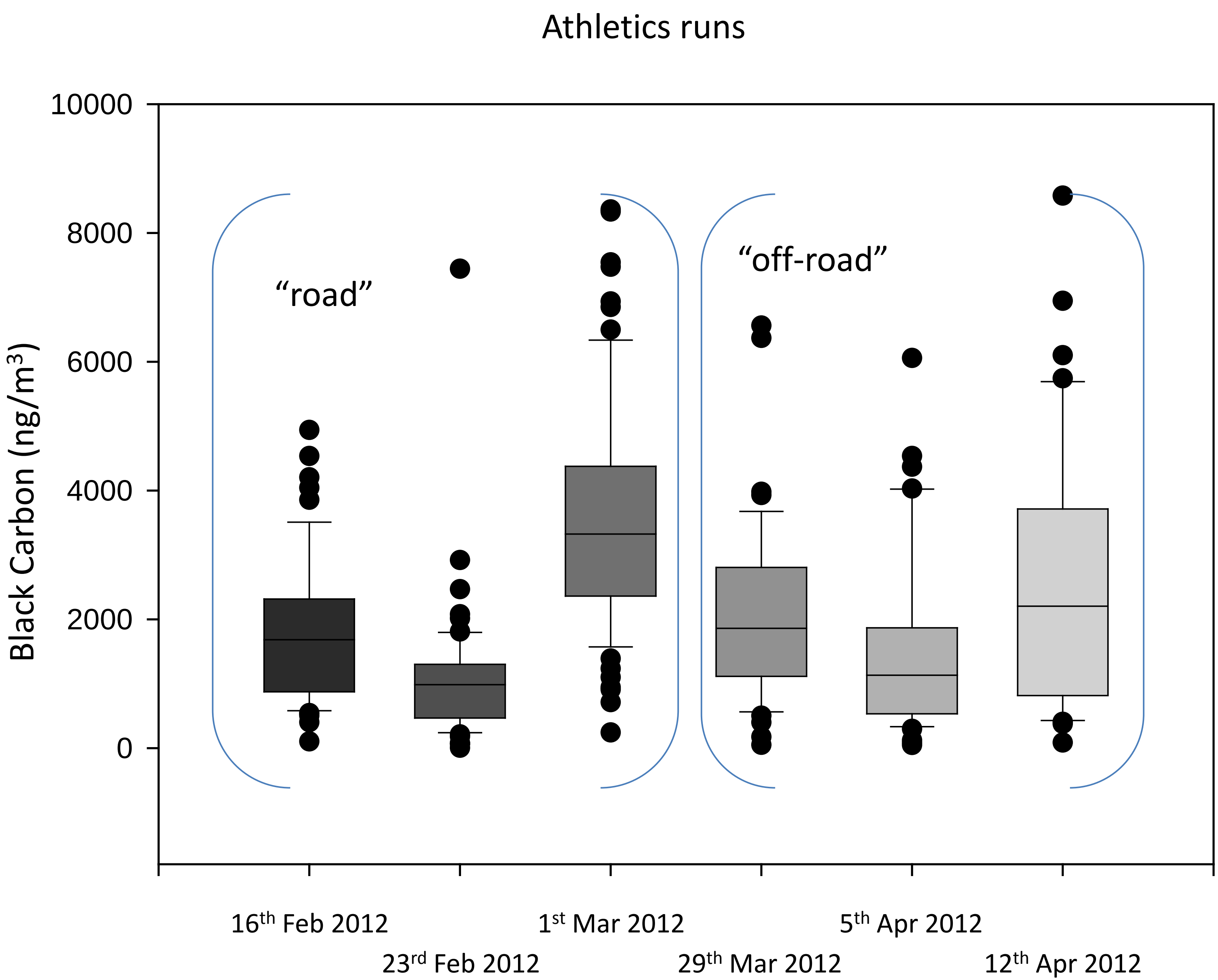
http://www.gmap-pedometer.com/?r=5402715

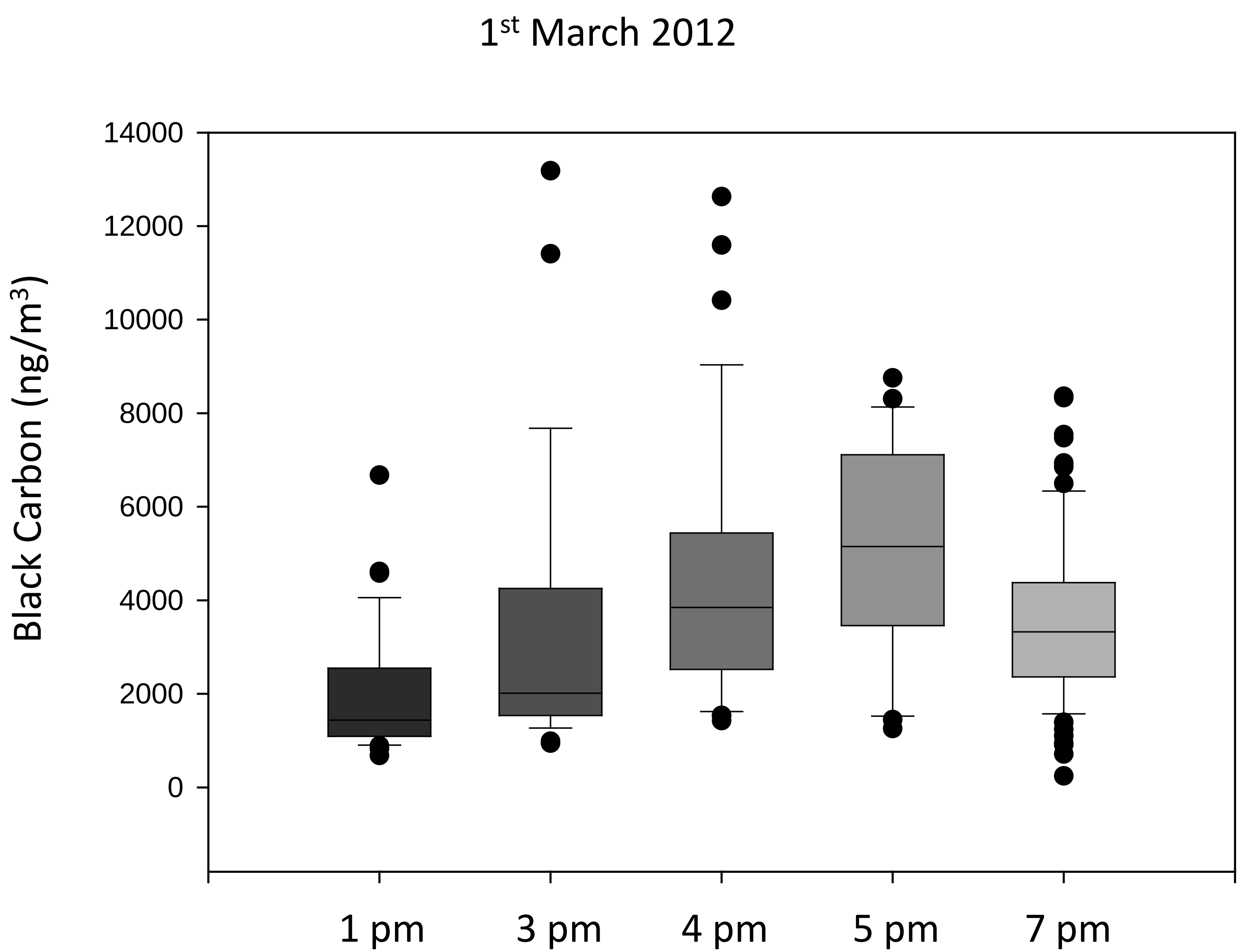


Run 6: 12th April 2012 country



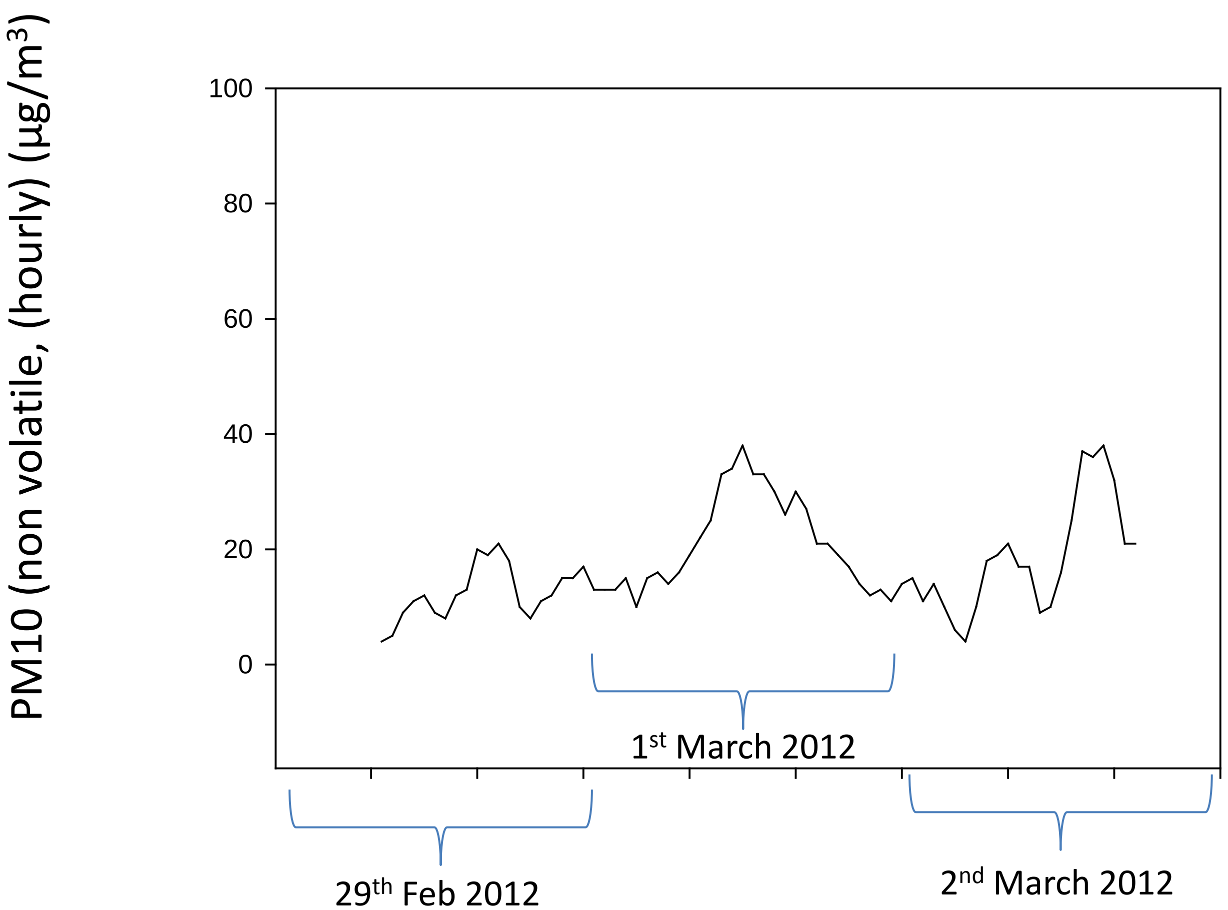
All runs
Black Carbon (ng/m3)
25000
20000
15000
10000
5000
0
Athletics runs
Cycling - run 3
Car commute


Athletics runs
Black Carbon (ng/m3)
10000
8000
6000
4000
2000
0
"road"
"off-road"
16th Feb 2012
23rd Feb 2012
1st Mar 2012
29th Mar 2012
5th Apr 2012
12th Apr 2012

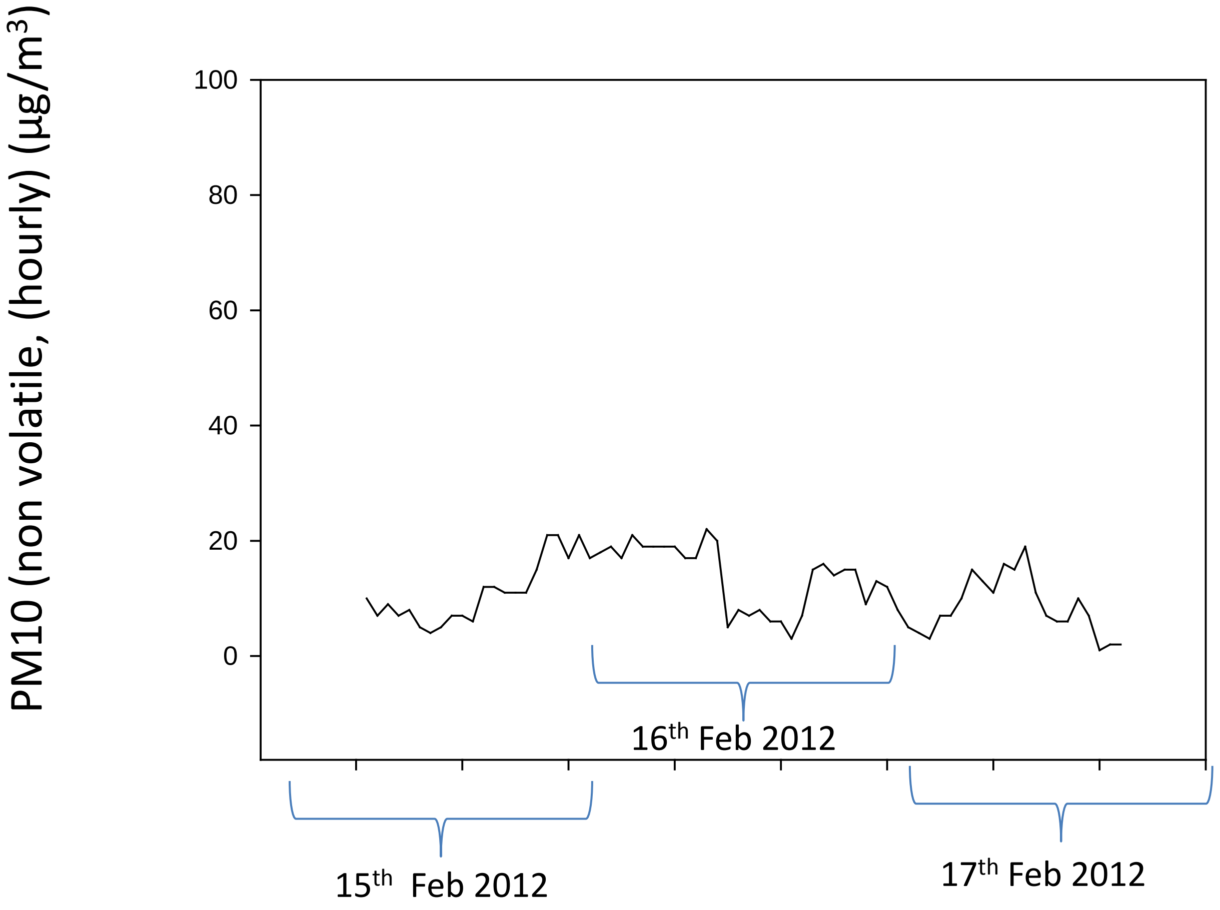


1st March 2012
Black Carbon (ng/m3)
14000
12000
10000
8000
6000
4000
2000
0
1 pm
3 pm
4 pm
5 pm
7 pm

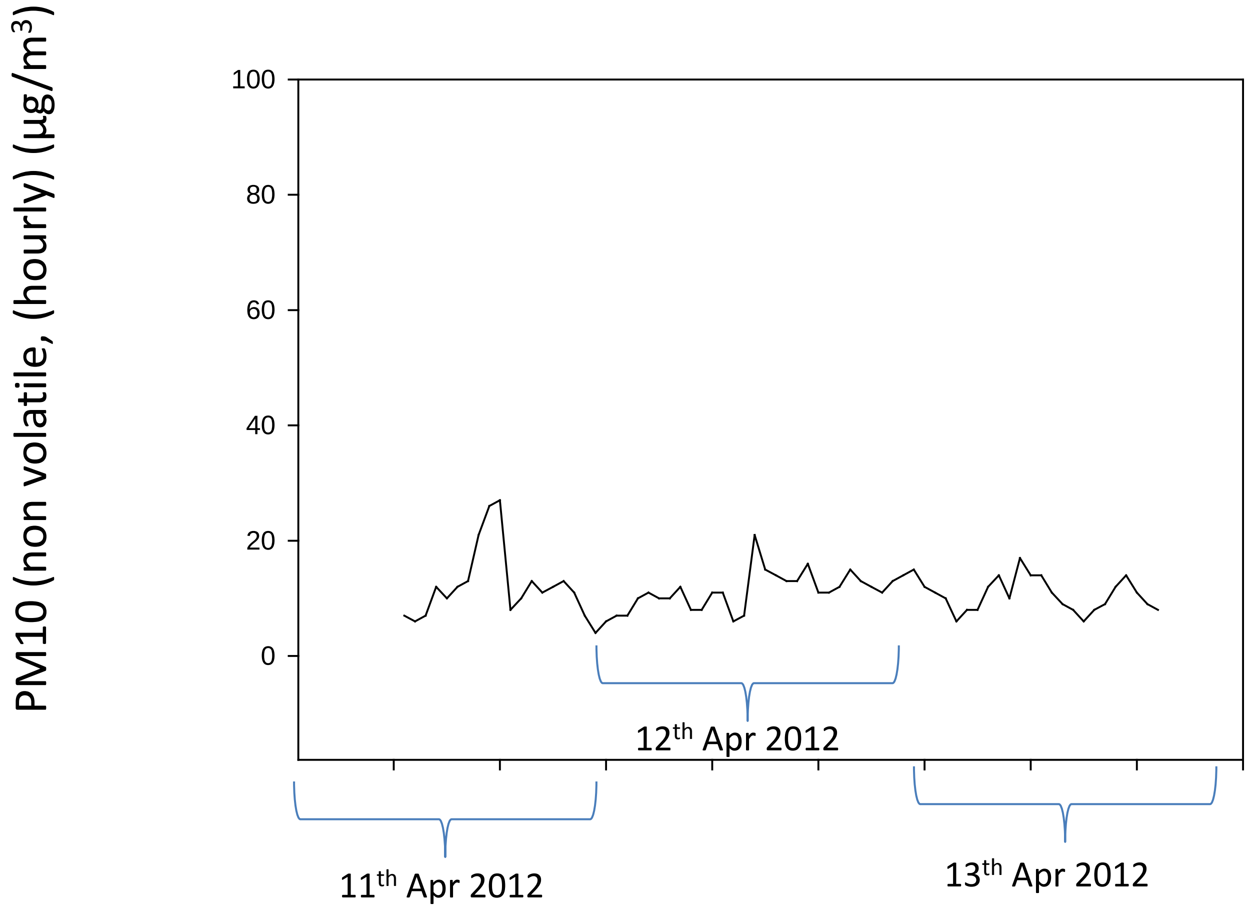
Broomhill, Glasgow (kerbside)



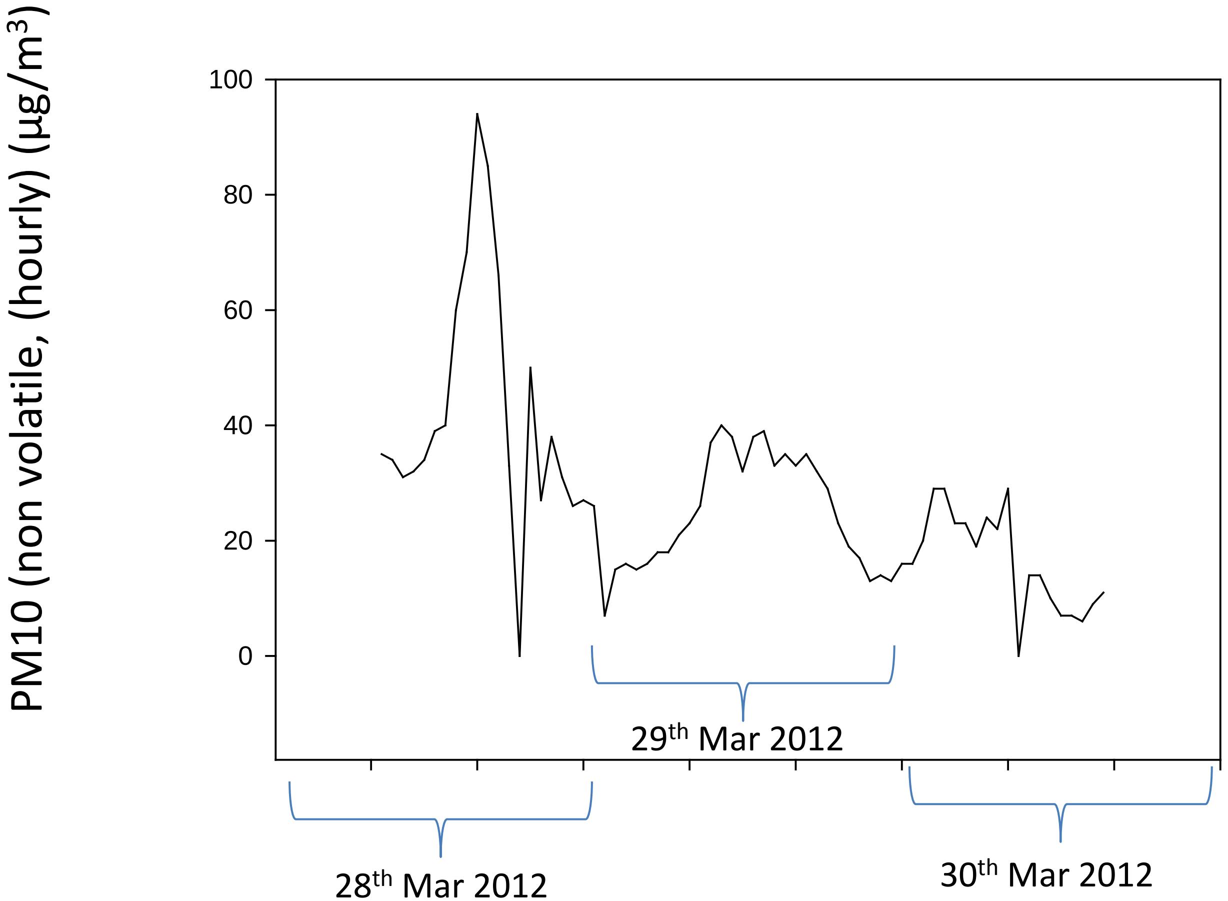
Broomhill, Glasgow (kerbside)



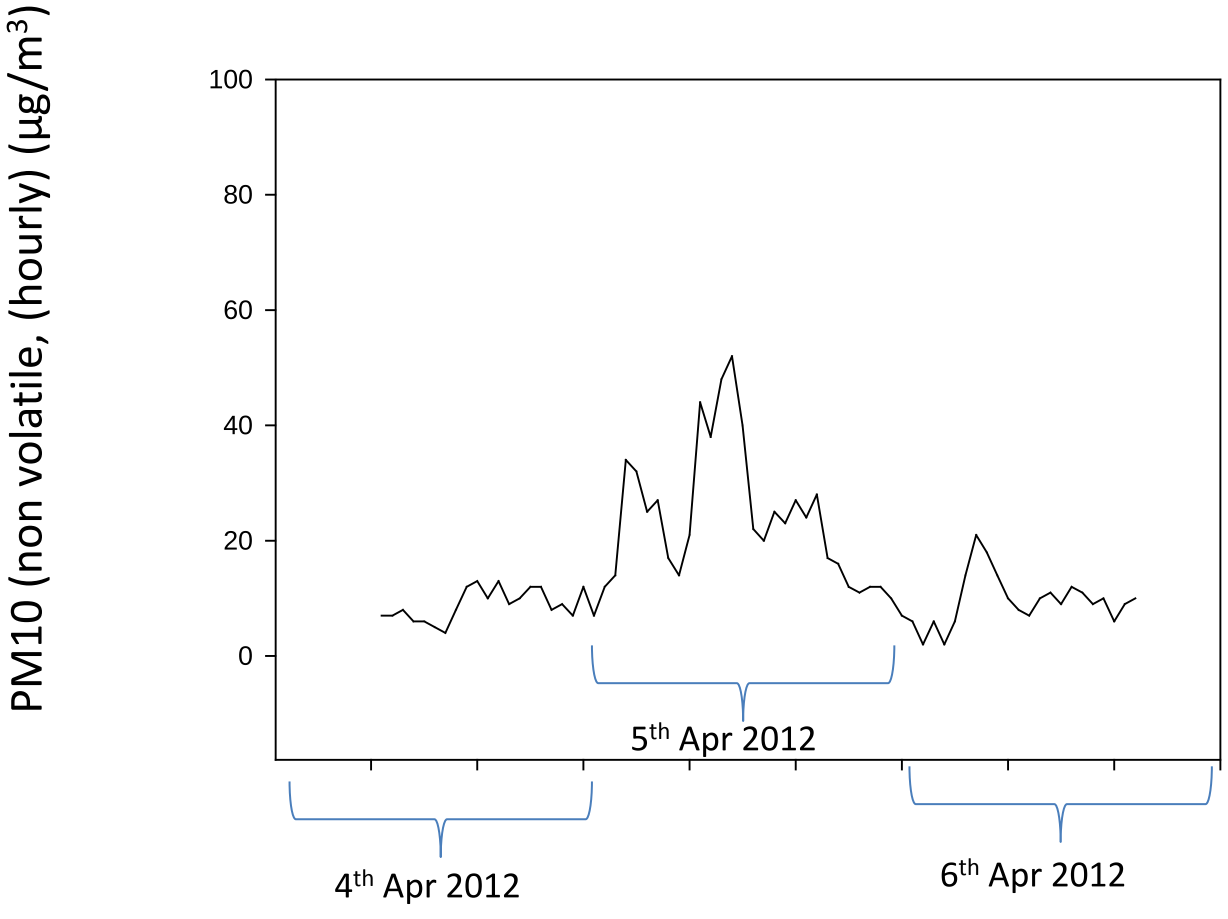
Broomhill, Glasgow (kerbside)

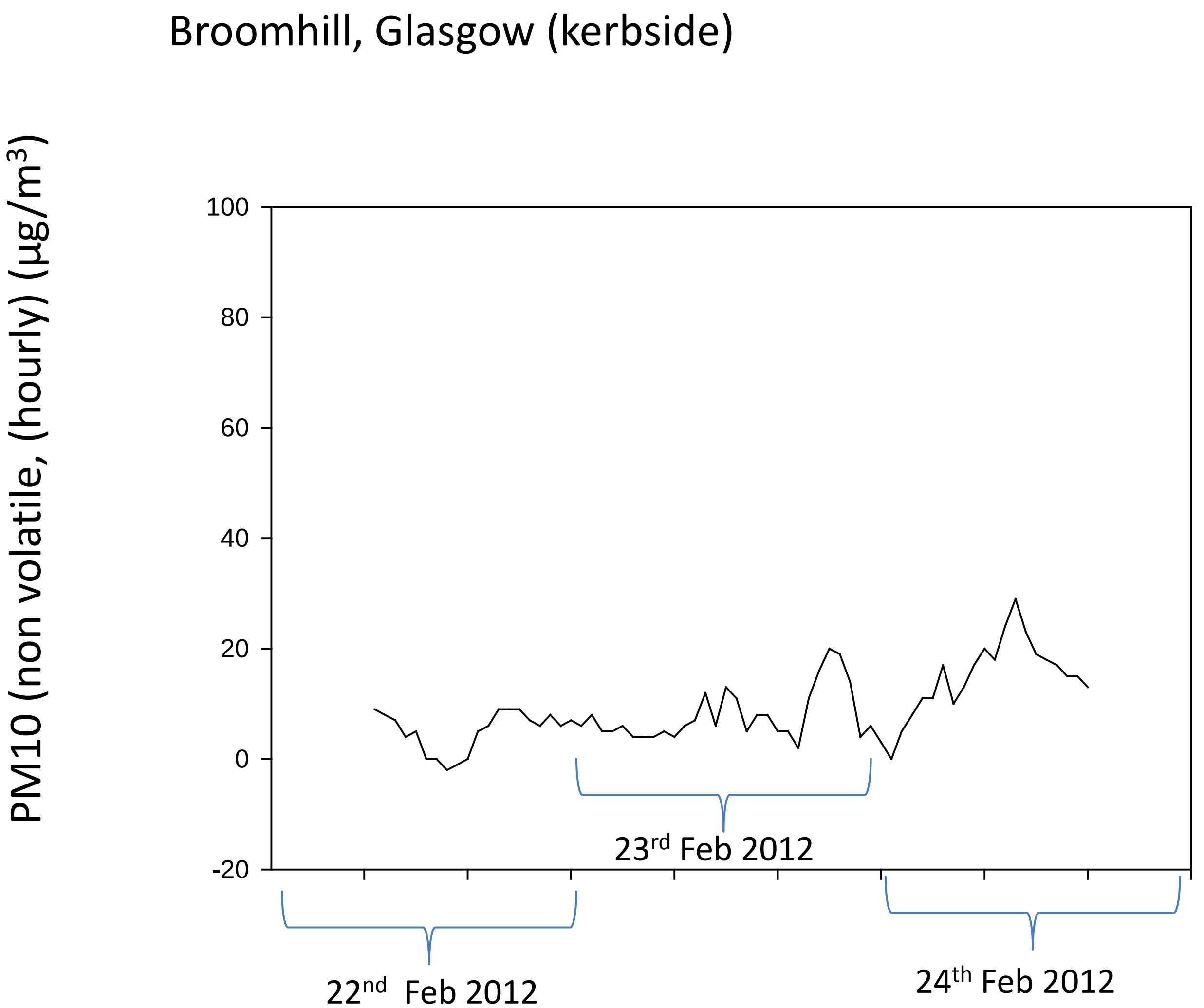


Broomhill, Glasgow (kerbside)



Broomhill, Glasgow (kerbside)




Broomhill, Glasgow (kerbside)
PM10 (non volatile, (hourly) (µg/m3)
100
80
60
40
20
0
-20
23rd Feb 2012
22nd Feb 2012
24th Feb 2012

Broomhill - longer hourly trends