



**DISCIPLINA: TÓPICOS ESPECIAIS – ESTATÍSTICA APLICADA**  
**À ENGENHARIA E CIÊNCIAS**

# **VARIAÇÕES NA EXPOSIÇÃO À POLUIÇÃO DO TRÁFEGO** **AO VIAJAR POR DIFERENTES MODOS DE TRANSPORTE** **EM UMA CIDADE COM BAIXA DENSIDADE E MENOR** **CONGESTIONAMENTO**

**JEFFERSON THIAGO MACEDO**

João Pessoa – Paraíba  
Julho – 2020

Environmental Pollution 181 (2013) 211–218

Contents lists available at SciVerse ScienceDirect

**Environmental Pollution**

journal homepage: [www.elsevier.com/locate/envpol](http://www.elsevier.com/locate/envpol)

**Variations in exposure to traffic pollution while travelling by different modes in a low density, less congested city** 

Simon Kingham<sup>a,\*</sup>, Ian Longley<sup>b</sup>, Jenny Salmond<sup>c</sup>, Woodrow Pattinson<sup>c</sup>, Kreepa Shrestha<sup>c</sup>

<sup>a</sup>Department of Geography, University of Canterbury, Christchurch, New Zealand  
<sup>b</sup>NIWA Ltd, Auckland, New Zealand  
<sup>c</sup>School of the Environment, University of Auckland, Auckland, New Zealand

---

**ARTICLE INFO**

**Article history:**  
 Received 22 December 2012  
 Received in revised form 15 June 2013  
 Accepted 17 June 2013

**Keywords:**  
 Air pollution exposure  
 Transport mode  
 Carbon monoxide  
 Ultrafine particles  
 Particulate matter

**ABSTRACT**

This research assessed the comparative risk associated with exposure to traffic pollution when travelling via different transport modes in Christchurch, New Zealand. Concentrations of PM<sub>10</sub>, UFPs and CO were monitored on pre-defined routes during the morning and evening commute on people travelling concurrently by car, bus and bicycle. It was found that car drivers were consistently exposed to the highest levels of CO; on-road cyclists were exposed to higher levels of all pollutants than off-road cyclists; car and bus occupants were exposed to higher average levels of UFP than cyclists, and travellers were occasionally exposed to very high levels of pollution for short periods of time. PM<sub>10</sub> and PM<sub>2.5</sub> were found to be poor indicators of exposure to traffic pollution. Studying Christchurch adds to our understanding as it was a lower density city with limited traffic congestion compared most other cities previously studied.

© 2013 Elsevier Ltd. All rights reserved.

---

**1. Introduction**

It is widely accepted that transport emitted air pollution has an adverse effect on health outcomes such as mortality, morbidity, and hospital admissions. In addition the economic costs of this can be great; for example in New Zealand it has been estimated that each year there are five hundred cases of premature mortality due to exposure to ambient particulate matter less than 10 micron in size (PM<sub>10</sub>), nitrogen dioxide (NO<sub>2</sub>) and carbon monoxide (CO) from vehicle emissions at a cost of nearly NZ\$500 m (Kingham et al., 2008). However, these studies (and similar ones) assume individual exposure is determined by air quality at their place of domestic residence (e.g. Beelen et al., 2007; Pope et al., 2009). As a consequence actual exposure to pollution may be significantly under-estimated as contributions from potentially high pollution micro-environments are not accounted for (Boogaard et al., 2009; Meng et al., 2012). For example a number of studies have examined personal pollution exposure on the journey to work and determined that, although temporally and spatially variable, individuals may be exposed to very high ambient pollutant concentrations in the transport microenvironment (e.g. Georgoulis et al., 2002; Kaur et al., 2007; Int Panis et al., 2010; Dons et al., 2011).

To date there is limited consistency in establishing which mode of transport (car, bus, bike, etc.) is associated with the highest exposures (Boogaard et al., 2009). Results vary both between and within studies which have been undertaken in a variety of different urban settings around the world. The vast majority of these studies have taken place in large urban areas with high population densities and significant traffic congestion such as London (Kaur et al., 2007), Barcelona (de Nazelle et al., 2012), Brussels (Int Panis et al., 2010), Utrecht (Boogaard et al., 2009) and Montreal (Hatzopoulou et al., 2013). Although differences in exposures have been found between cities which experience different levels of congestion (Int Panis et al., 2010), little, if anything is known about the situation in smaller urban areas, with lower population density, and less congestion. Furthermore there is no data from cities surrounded by comparatively pristine environments, nor cities located in the Southern Hemisphere (de Nazelle et al., 2012) where traffic conditions, emissions profiles and meteorological conditions may be significantly different. Yet, there are many cities in the world that possess these characteristics. This purpose of this research is to assess the comparative risk associated with exposure to traffic pollution when travelling on car, bus and bike in an urban area with

\* Corresponding author.  
 E-mail address: [simon.kingham@canterbury.ac.nz](mailto:simon.kingham@canterbury.ac.nz) (S. Kingham).

0269-7491/\$ – see front matter © 2013 Elsevier Ltd. All rights reserved.  
<http://dx.doi.org/10.1016/j.envpol.2013.06.030>

Revista: **Environmental Pollution**

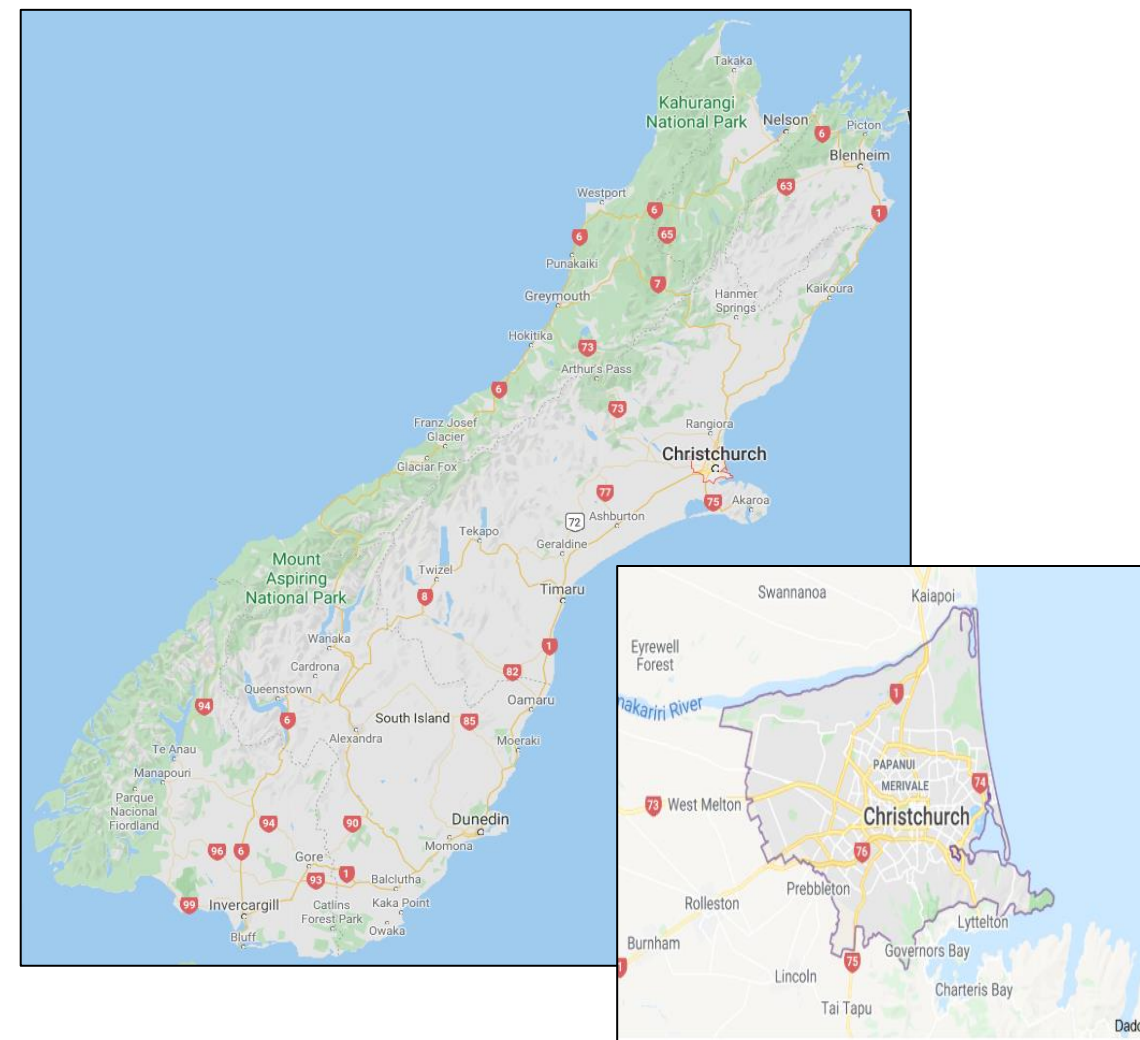
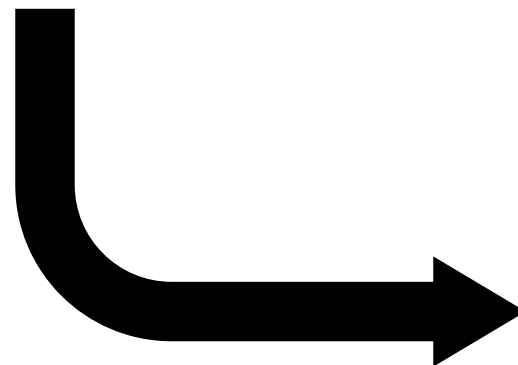
Site: <https://www.journals.elsevier.com/environmental-pollution>

Fator de impacto: **5,714**

A revista **Poluição Ambiental** acolhe envios de trabalhos de alta qualidade em todos os aspectos de poluição ambiental e medidas de mitigação relacionadas ao ecossistema e à saúde humana

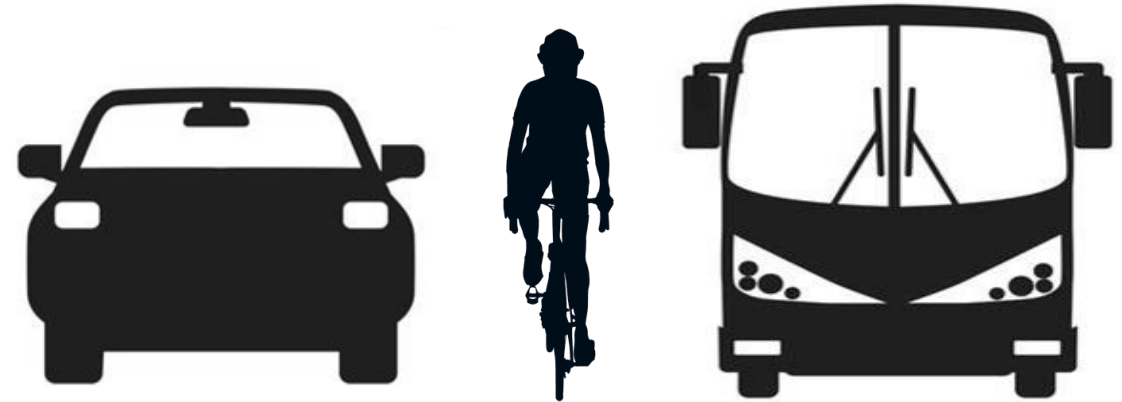
Referência: KINGHAM, Simon; LONGLEY, Ian; SALMOND, Jenny; PATTINSON, Woodrow; SHRESTHA, Kreepa. Variations in exposure to traffic pollution while travelling by different modes in a low density, less congested city. **Environmental Pollution**, [s.l.], v. 181, p. 211-218, out. 2013. Elsevier BV. <http://dx.doi.org/10.1016/j.envpol.2013.06.030>

- ❑ Pesquisa que avaliou o risco comparativo associado à exposição à poluição do tráfego ao viajar através de diferentes modos de transporte em **Christchurch**, Nova Zelândia.



**Fig. 1-** Ilha do Sul da Nova Zelândia.  
Em destaque menor: cidade de Christchurch.

□ Monitorar as concentrações de **material particulado** ( $PM_1$ ,  $PM_{2,5}$  e  $PM_{10}$ ), **partículas ultrafinas** (UFPs) e **monóxido de carbono** (CO) em rotas pré-definidas durante a manhã e noite de pessoas viajando simultaneamente de **carro, bicicleta e ônibus**.



- ❑ Tentar compreender como a cidade de Christchurch se comporta em relação ao tema investigado, quando a mesma apresenta particularidades diferentes de estudos que compreendem a mesma metodologia.



**Fig. 2-** Pontos turísticos de Christchurch (de cima para baixo): Bridge of Remembrance, Kate Sheppard Memorial Christchurch e Universidade de Canterbury.

METODOLOGIA

POLUENTES, INSTRUMENTOS  
E EQUIPAMENTO

REGIME DE  
MONITORAMENTO

ÁREA DE ESTUDO



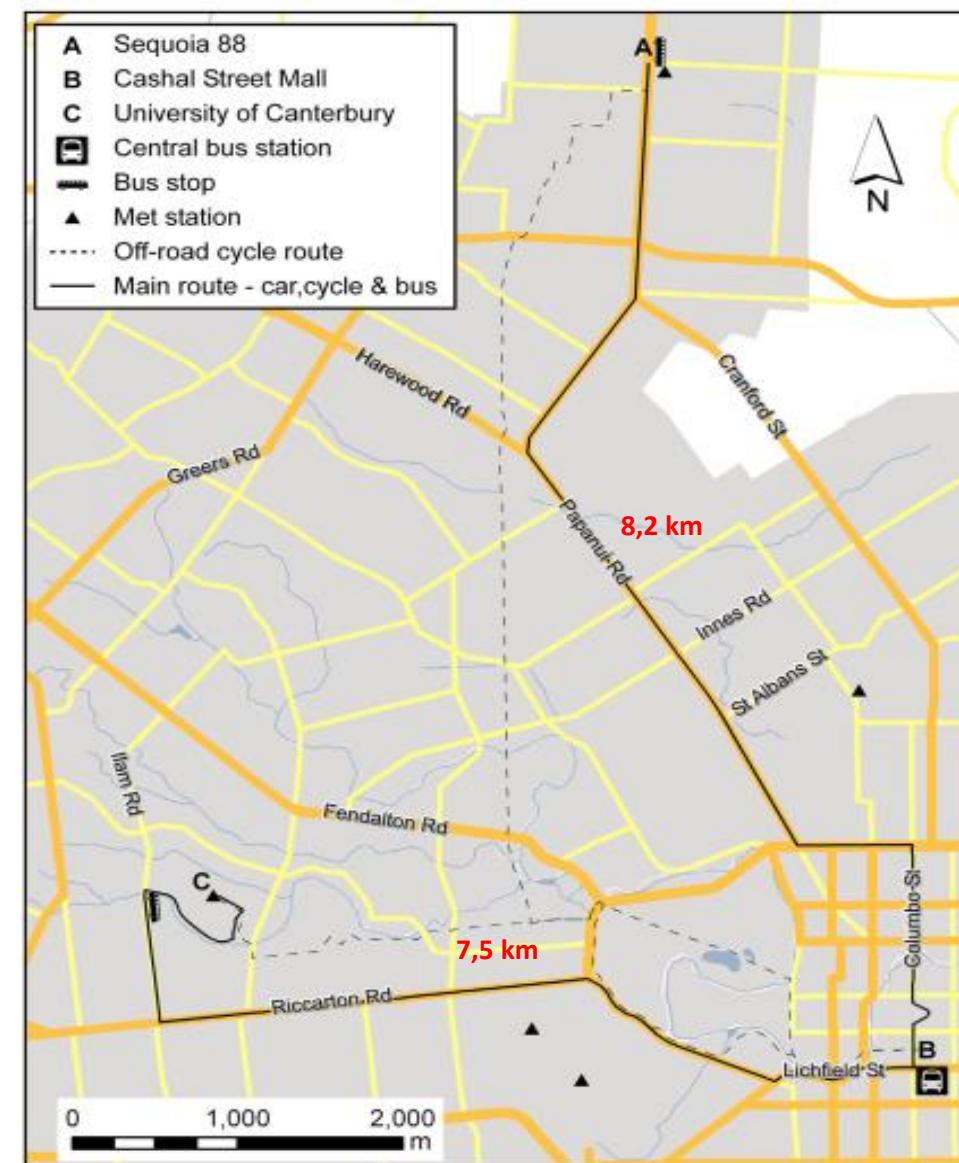
# METODOLOGIA

POLUENTES,  
INSTRUMENTOS E  
EQUIPAMENTO

REGIME DE  
MONITORAMENTO

ÁREA DE ESTUDO

**Fig. 3-** Rota de amostragem em Christchurch. As viagens matinais foram do estacionamento do Sequoia 88, um restaurante no subúrbio de Redwood (A) até a central de ônibus (B) e depois fora da cidade central até a Universidade de Canterbury (C). À tarde, a jornada foi invertida.



# METODOLOGIA

POLUENTES,  
INSTRUMENTOS E  
EQUIPAMENTO

REGIME DE  
MONITORAMENTO

ÁREA DE ESTUDO

**Table 1**

Summary of number of trips and simultaneously sampled pairs of different transport modes (car, bus, on-road bike and off-road bike) for each pollutant (carbon monoxide, particulates and ultrafine particles).

Pollutant	Transport mode	<i>N</i>	Simultaneously paired with bike off-road	Simultaneously paired with bike on-road	Simultaneously paired with bus
Carbon monoxide (CO)	Car	49	46	45	47
	Bus	52	46	47	
	Bike on-road	49	43		
	Bike off-road	48			
Particulate matter (PM <sub>10, 2.5</sub> & 1)	Car	17	15	2	13
	Bus	42	35	28	
	Bike on-road	32	27		
	Bike off-road	46			
Ultrafine particles (UFP)	Car	42	27	39	12
	Bus	12	0	12	
	Bike on-road	44	27		
	Bike off-road	34			





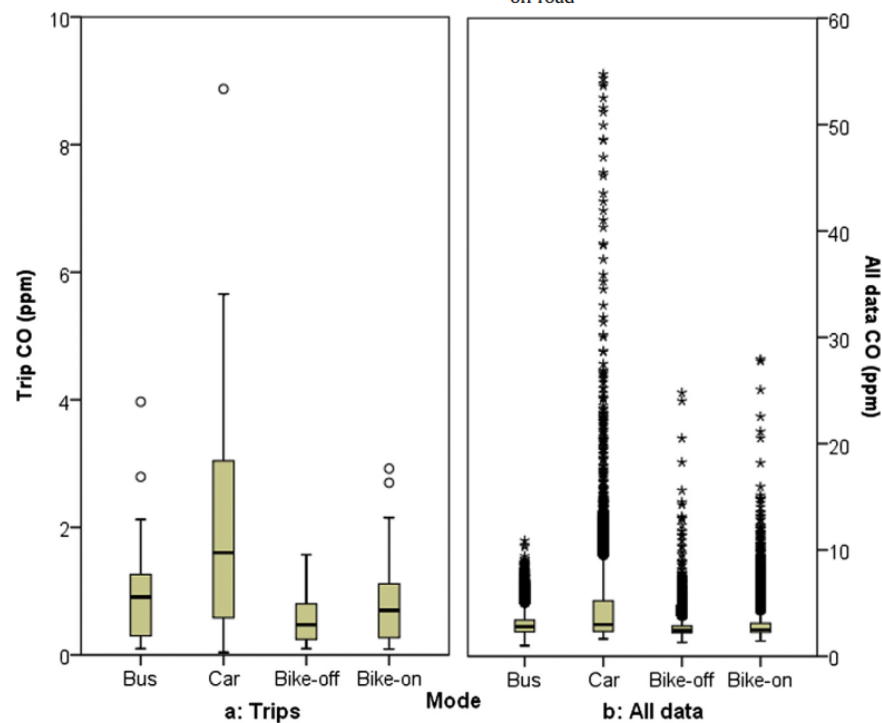
- Box-plot:** (a) Viagens e (b) Todos os dados coletados a cada 6s;
- Falta de dados;
- Para contornar isso, foi comparado as proporções de exposição a poluição entre diferentes modos **monitorados simultaneamente**, conforme mostrado na **Tab. 2**;
- Aqui uma proporção (média e mediana são mostradas) **acima de 1 indica que a proporção do primeiro modo de transporte nomeado foi maior que a do segundo nomeado**;
- Além de algumas estatísticas descritivas adicionais, também são apresentados valores para o **teste de Wilcoxon**.

# Monóxido de carbono (CO)

**Table 2**

Descriptive statistics for ratios of pollutant levels (carbon monoxide, particulates and ultrafine particles) by transport modes (car, bus, on-road bike and off-road bike) for simultaneously sampled trips. In addition to the median, minimum, maximum and standard deviations of the ratios for the paired transport modes for the different pollutants, the number of occasions each paired mode is greater than the other is given, as well as Wilcoxon signed-rank test *P*-values which tell us whether the two values are statistically significantly different.

Pollutant	Paired modes	Number of paired modes	Median ratio	Min ratio	Max ratio	Std. Dev. of ratios	Number of times first mode > second mode	Number of times second mode > first mode	<i>P</i>
Carbon monoxide (CO)	Car:Bus	47	1.8	0.2	42.8	6.3	Car > Bus: 37	Bus > Car: 10	<0.01
	Car:Bike on road	45	1.5	0.1	46.9	7.3	Car > Bike on: 32	Bike on > Car: 13	<0.01
	Car:Bike off road	46	2.5	0.1	37.3	8.0	Car > Bike off: 36	Bike off > Car: 10	<0.01
	Bus:Bike on road	47	1.1	0.1	14.9	2.2	Bus > Bike on: 25	Bike on > Bus: 22	0.43
	Bus:Bike off road	46	1.4	0.5	11.2	1.8	Bus > Bike off: 31	Bike off > Bus: 15	<0.01
	Bike on road:Bike off road	43	1.6	0.2	9.5	1.8	Bike on > Bike off: 29	Bike off > Bike on: 14	<0.01



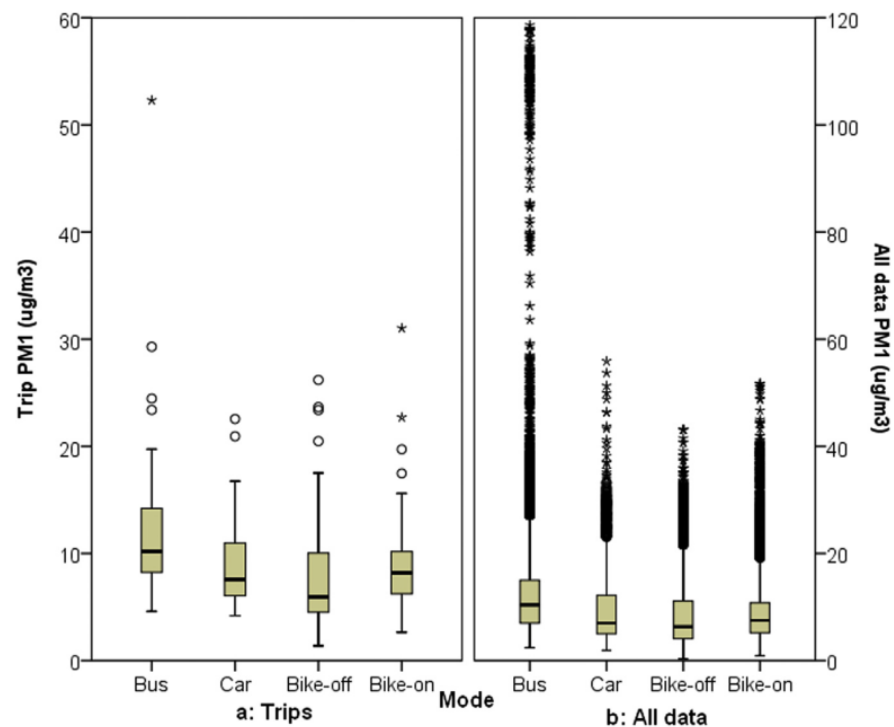
**Fig. 4-** Box-plot dos níveis médios de CO por modo (ônibus, carro, bicicleta on-off-road) para (a) Viagens (b) Todos os dados coletados a cada 6s.

- ❑ Comparação dos resultados com outros estudos desenvolvidos em outras cidades ao redor do mundo;
- ❑ Carros expostos a maiores níveis de CO;
- ❑ Diferenças mais sutis foram encontrados entre usuários de ônibus e bicicleta.

Material  
Particulado (PM)**Table 2**

Descriptive statistics for ratios of pollutant levels (carbon monoxide, particulates and ultrafine particles) by transport modes (car, bus, on-road bike and off-road bike) for simultaneously sampled trips. In addition to the median, minimum, maximum and standard deviations of the ratios for the paired transport modes for the different pollutants, the number of occasions each paired mode is greater than the other is given, as well as Wilcoxon signed-rank test *P*-values which tell us whether the two values are statistically significantly different.

Pollutant	Paired modes	Number of paired modes	Median ratio	Min ratio	Max ratio	Std. Dev. of ratios	Number of times first mode > second mode	Number of times second mode > first mode	<i>P</i>
Particulates less than 1 micron (PM <sub>1</sub> )	Car:Bus	13	0.8	0.6	1.3	0.2	Car > Bus: 3	Bus > Car: 10	0.22
	Car:Bike on road	2	2.1	1.9	2.3	0.3	Car > Bike on: 2	Bike on > Car: 0	0.18
	Car:Bike off road	15	1.4	1.0	4.4	1.0	Car > Bike off: 14	Bike off > Car: 1	<0.01
	Bus:Bike on road	28	1.2	0.7	3.0	0.6	Bus > Bike on: 22	Bike on > Bus: 6	<0.01
	Bus:Bike off road	35	1.5	0.7	3.4	0.7	Bus > Bike off: 30	Bike off > Bus: 5	<0.01
	Bike on road:Bike off road	27	1.2	0.3	1.9	0.3	Bike on > Bike off: 24	Bike off > Bike on: 3	<0.01



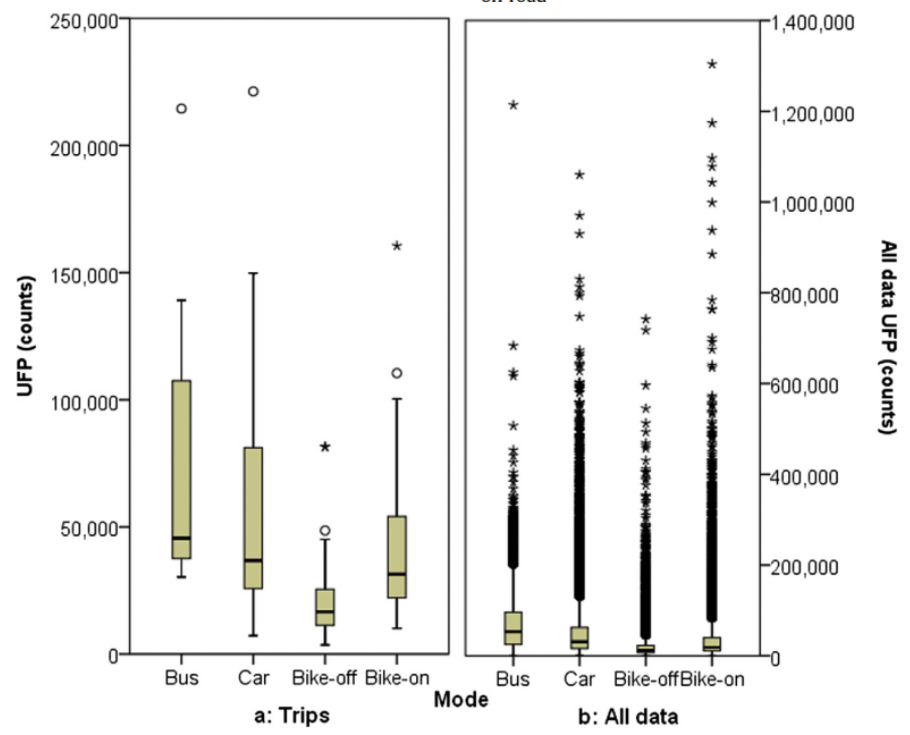
**Fig. 5-** Box-plot dos níveis médios de PM<sub>1</sub> por modo (ônibus, carro, bicicleta on-off-road) para (a) Viagens (b) Todos os dados coletados a cada 6s.

- Comparação a exposição às concentrações entre o observado para material particulado (PM<sub>10</sub>) e o monóxido de carbono;
- Resultados inéditos em relação aos ciclistas off-road;
- Comparações com outros estudos para material particulado de 2,5 micromêtros);
- Os resultados na fração de tamanho PM<sub>1</sub> são mais consistentes com estudos anteriores.

Partículas ultrafinas (UFP)

**Table 2**  
Descriptive statistics for ratios of pollutant levels (carbon monoxide, particulates and ultrafine particles) by transport modes (car, bus, on-road bike and off-road bike) for simultaneously sampled trips. In addition to the median, minimum, maximum and standard deviations of the ratios for the paired transport modes for the different pollutants, the number of occasions each paired mode is greater than the other is given, as well as Wilcoxon signed-rank test *P*-values which tell us whether the two values are statistically significantly different.

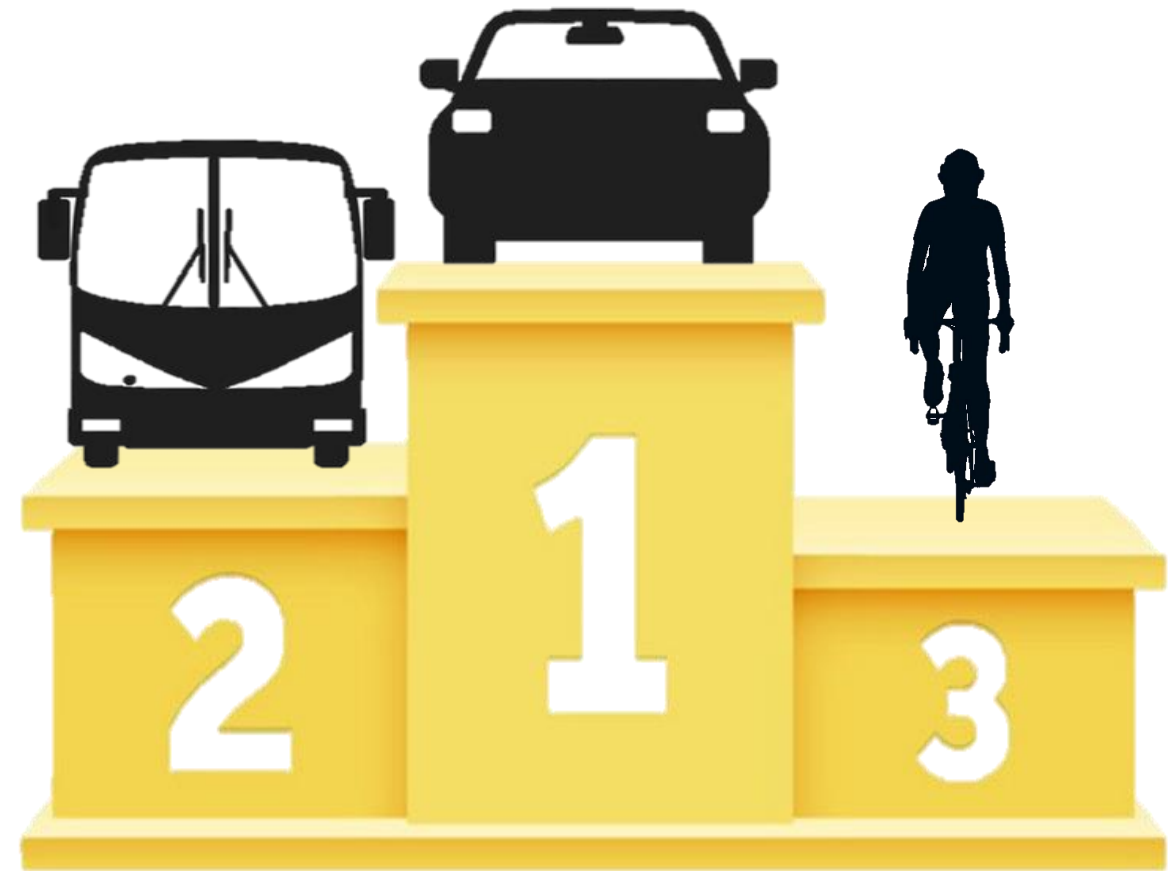
Pollutant	Paired modes	Number of paired modes	Median ratio	Min ratio	Max ratio	Std. Dev. of ratios	Number of times first mode > second mode	Number of times second mode > first mode	<i>P</i>
Ultrafine particles (UFP)	Car:Bus	12	1.0	0.4	1.9	0.4	Car > Bus: 7	Bus > Car: 5	0.58
	Car:Bike on road	39	1.1	0.5	2.8	0.6	Car > Bike on: 24	Bike on > Car: 15	0.09
	Car:Bike off road	27	2.1	0.2	5.4	1.2	Car > Bike off: 26	Bike off > Car: 1	<0.01
	Bus:Bike on road	12	1.3	1.0	2.2	0.4	Bus > Bike on: 12	Bike on > Bus: 0	<0.01
	Bus:Bike off road	0							
	Bike on road:Bike off road	27	2.2	0.2	4.9	1.2	Bike on > Bike off: 21	Bike off > Bike on: 6	<0.01



- ❑ Comparação com outros estudos;
- ❑ Exposição mais alta pelos passageiros de ônibus, seguido pelo motorista e depois pelos ciclistas;
- ❑ Ônibus e carros oferecem alguma proteção contra exposições agudas muito altas, mas pouca proteção a exposições médias de longo prazo.

**Fig. 6-** Box-plot dos níveis médios de UFP por modo (ônibus, carro, bicicleta on-off-road) para (a) Viagens (b) Todos os dados coletados a cada 6s.

- ❑ Os resultados mostram que os passageiros estão geralmente expostos a **níveis mais baixos de CO** do que em outras cidades, mas **estão expostos a níveis semelhantes** de  $PM_{10}$  e UFP;
- ❑ **Frações maiores de partículas, são indicadores fracos** de emissão de tráfego em estudos que examinam a exposição ao viajante;
- ❑ Os ocupantes de carro estão **expostos à pior qualidade do ar.**



**OBRIGADO!**