Healthy Urban Atmospheres

Observing and modelling particle number concentrations inside vehicles in busy traffic

NIWA
Taihoro Nukurangi

Ian Longley, Sharleen Harper, Gustavo Olivares, Nick Talbot, Guy Coulson
National Institute of Water & Atmospheric Research
Auckland, New Zealand

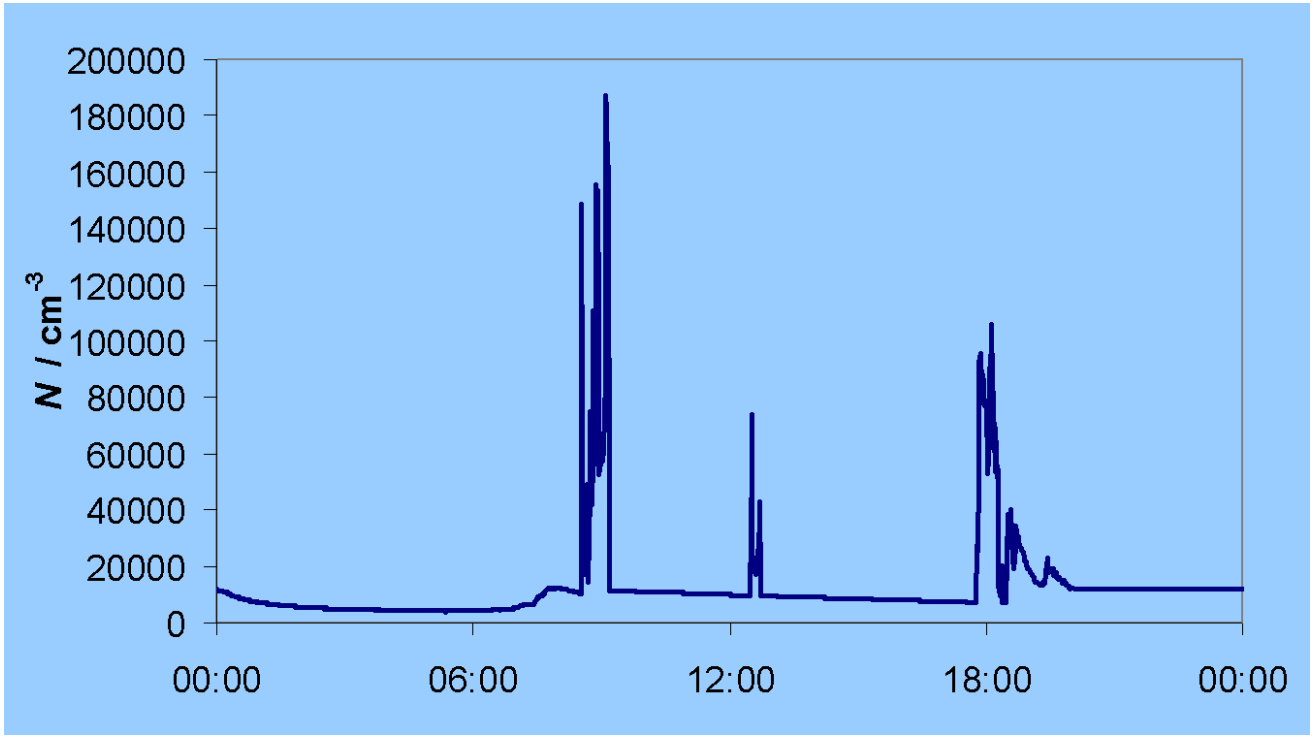
www.niwa.co.nz

Observing and modelling particle number concentrations inside vehicles in busy traffic

Particle number concentration exposure diary

Measurements using TSI P-Trak in Manchester, UK

(Acknowledgements Anna Leavey, formerly of University of Manchester)



Landcare Research Manaaki Whenua

Environet ltd Air Quality & IT Specialists

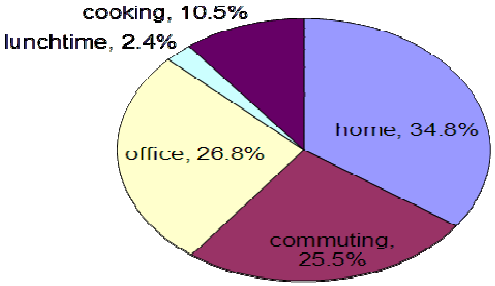
UC UNIVERSITY OF CANTERBURY Te Whare Wānanga o Waitaha CHRISTCHURCH NEW ZEALAND

Golder Associates

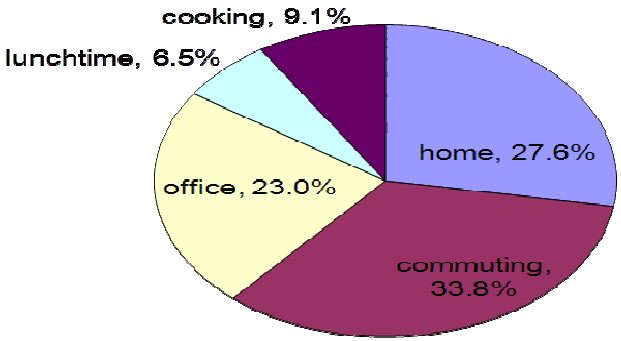
NIWA Taihoro Nukurangi

Contribution to inhaled dose

Constant breathing rate



Variable breathing rate



Commuting duration 76 minutes, or 5 % of day

Data from Manchester-based pilot study

Landcare Research Manaaki Whenua

Environet ltd Air Quality & IT Specialists

UC University of Canterbury Te Whare Wānanga o Waitaha Christchurch New Zealand

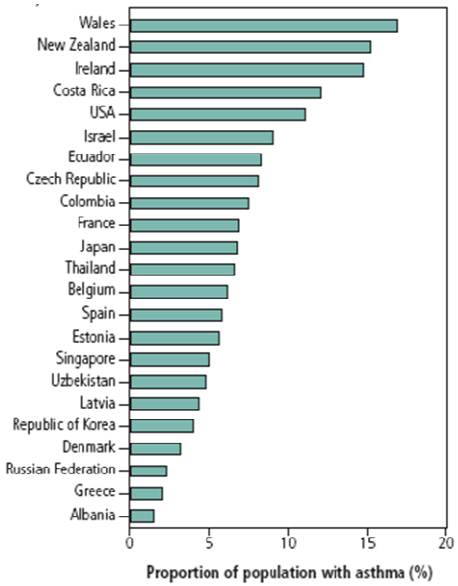
Golder Associates

NIWA Taihoro Nukurangi

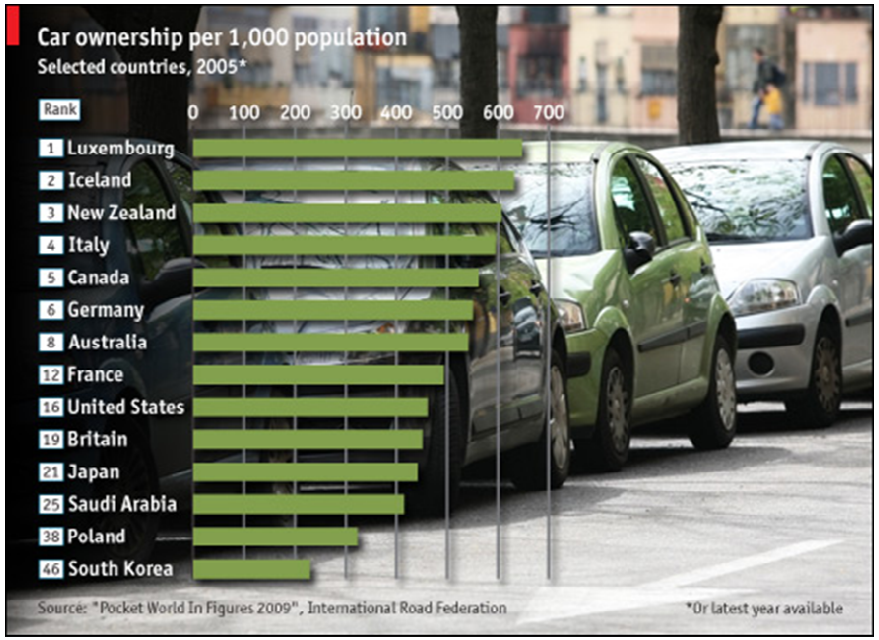
Observing and modelling particle number concentrations inside vehicles in busy traffic

New Zealand, Auckland, cars and health

- 1/3 of estimated health costs due to air pollution in NZ is incurred in Auckland
- Auckland has 1.3m people and 1m vehicles
- 90% commuting trips in Auckland by car
- 125,000 children in Auckland travel to school by car



Adapted from Masoli et al. (6).



Landcare Research Manaaki Whenua

Environet ltd Air Quality & IT Specialists

UC University of Canterbury Te Whare Wānanga o Waitaha Christchurch New Zealand

Golder Associates

NIWA Taihoro Nukurangi

Observing and modelling particle number concentrations inside vehicles in busy traffic

Auckland-based study approach (to date)

Long-term aim of systematic semi-empirical prediction of exposure of large population

1. Trials: exploratory in-car observations in Auckland traffic
2. Simple high-res air exchange modelling
3. Semi-controlled study of car-related variables
4. Intensive observations of commuting in Auckland rush-hour (PNC, PM, CO)

Landcare Research Manaaki Whenua | Environet ltd Air Quality & IT Specialists | UC University of Canterbury Te Whare Wānanga o Waitaha Christchurch New Zealand | Golder Associates | NIWA Taihoro Nukurangi

Observing and modelling particle number concentrations inside vehicles in busy traffic

Observations in “normal” conditions

Landcare Research Manaaki Whenua

Environet ltd Air Quality & IT Specialists

UC UNIVERSITY OF CANTERBURY Te Whare Wānanga o Waitaha CHRISTCHURCH NEW ZEALAND

Golder Associates

NIWA Taihoro Nukurangi

Observing and modelling particle number concentrations inside vehicles in busy traffic

Observations of in-vehicle PNC in ‘normal’ conditions

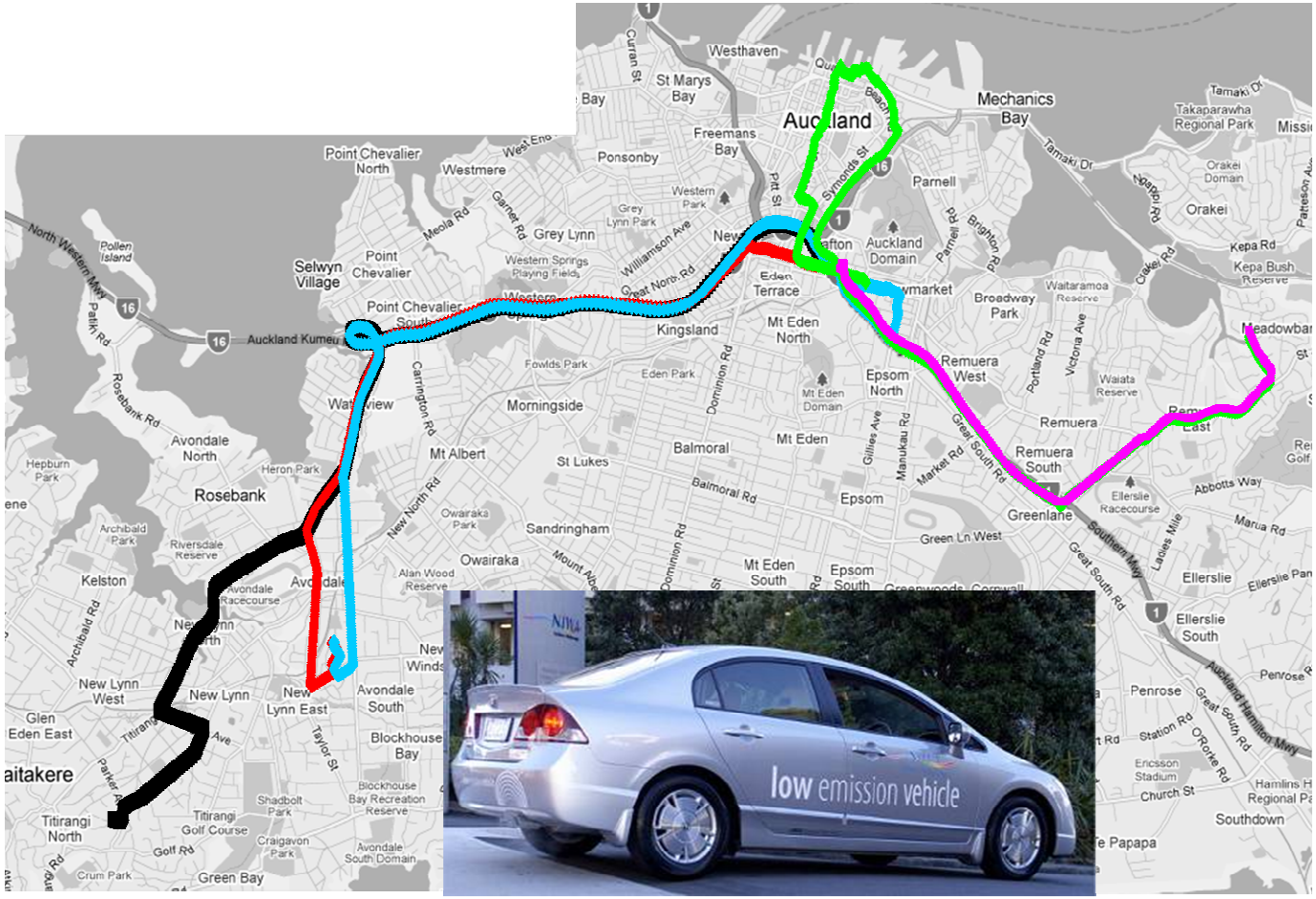
- TSI P-Trak in inter-peak studies
- TSI 3007 in peak traffic studies (Aug 2009)
- Honda Civic, Toyota Camry, Ford Falcon
- Total dataset: 15 hrs over 8 days
- “normal” ventilation

- Inter-peak traffic:
  - Mean of all motorway segments : 27,000 cm^{-3}
  - Mean of all CBD segments: 20,000 cm^{-3}
  - Mean of all non-CBD segments: 14,000 cm^{-3}
  - Typical background during campaign: 3,000 cm^{-3}
- Peak traffic:
  - Mean of all motorway segments : 63,000 cm^{-3}
  - Mean of all non-motorway segments: 26,000 cm^{-3} (background ~4,000 cm^{-3})

Landcare Research Manaaki Whenua | Environet ltd Air Quality & IT Specialists | UC University of Canterbury Te Whare Wānanga o Waitaha Christchurch New Zealand | Golder Associates | NIWA Taihoro Nukurangi

Observing and modelling particle number concentrations inside vehicles in busy traffic

Example study routes (from 2007 pilot study)



Landcare Research Manaaki Whenua

Environet ltd Air Quality & IT Specialists

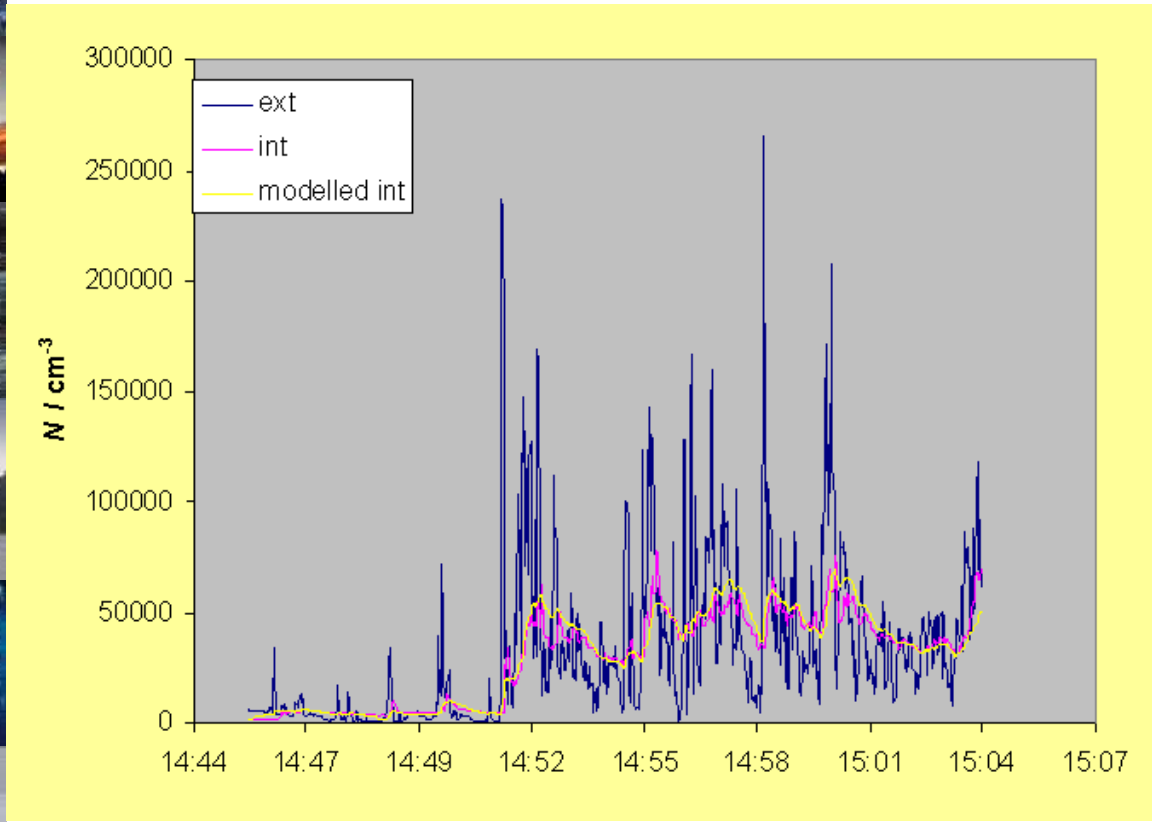
UC UNIVERSITY OF CANTERBURY Te Whare Wānanga o Waitaha CHRISTCHURCH NEW ZEALAND

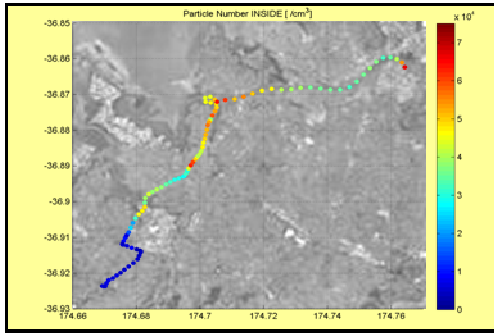
Golder Associates

NIWA Taihoro Nukurangi

Observing and modelling particle number concentrations inside vehicles in busy traffic

Initial trial example, Honda Civic





Landcare Research Manaaki Whenua

Environet ltd Air Quality & IT Specialists

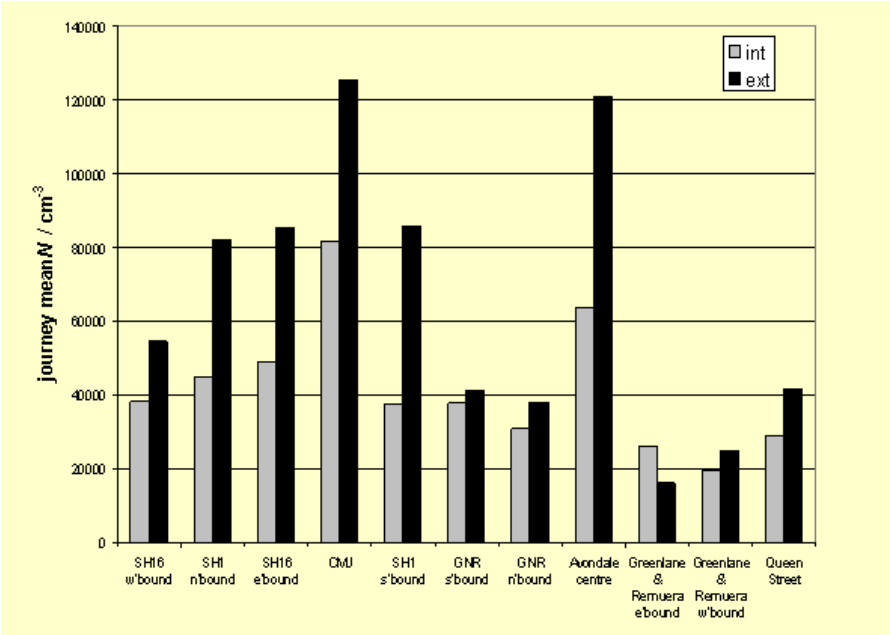
UC UNIVERSITY OF CANTERBURY Te Whare Wānanga o Waitaha CHRISTCHURCH NEW ZEALAND

Golder Associates

NIWA Taihoro Nukurangi

Observing and modelling particle number concentrations inside vehicles in busy traffic

Observed Journey segment details

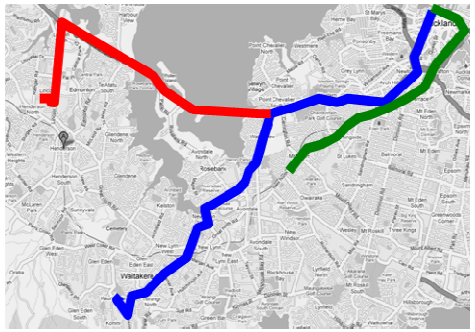


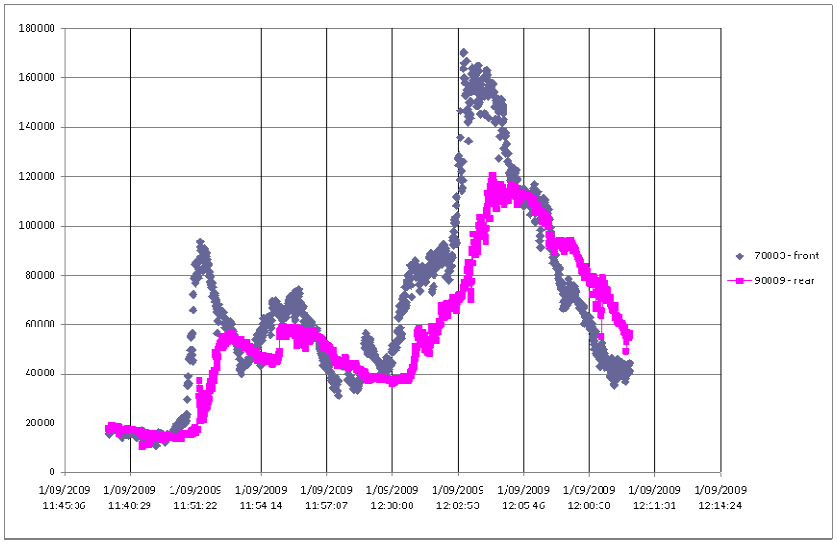
1. internal < external, as vehicle acts as band-pass filter for brief spikes
2. highest values in congested traffic at Central Motorway Junction (CMJ) and suburban high street (Avondale)
3. next highest concentrations on free-flowing motorways
4. ΔN much lower on non-motorway sections – external less spiky

Landcare Research Manaaki Whenua | Environet ltd Air Quality & IT Specialists | UC University of Canterbury Te Whare Wānanga o Waitaha Christchurch New Zealand | Golder Associates | NIWA Taihoro Nukurangi

Observing and modelling particle number concentrations inside vehicles in busy traffic

WAIVE (Waitakere to Auckland In-Vehicle Exposure) 2009





Landcare Research Manaaki Whenua

Environet ltd Air Quality & IT Specialists

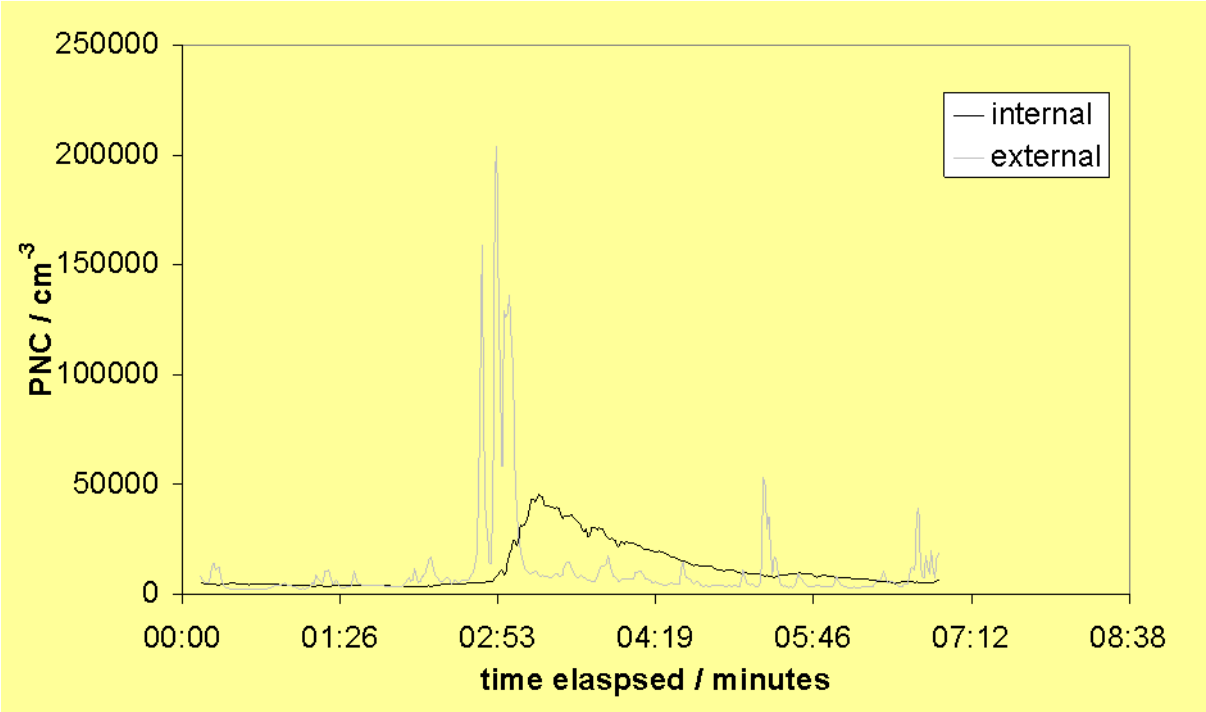
UC UNIVERSITY OF CANTERBURY Te Whare Wānanga o Waitaha CHRISTCHURCH NEW ZEALAND

Golder Associates

NIWA Taihoro Nukurangi

Observing and modelling particle number concentrations inside vehicles in busy traffic

Observational features #1: response to intersections

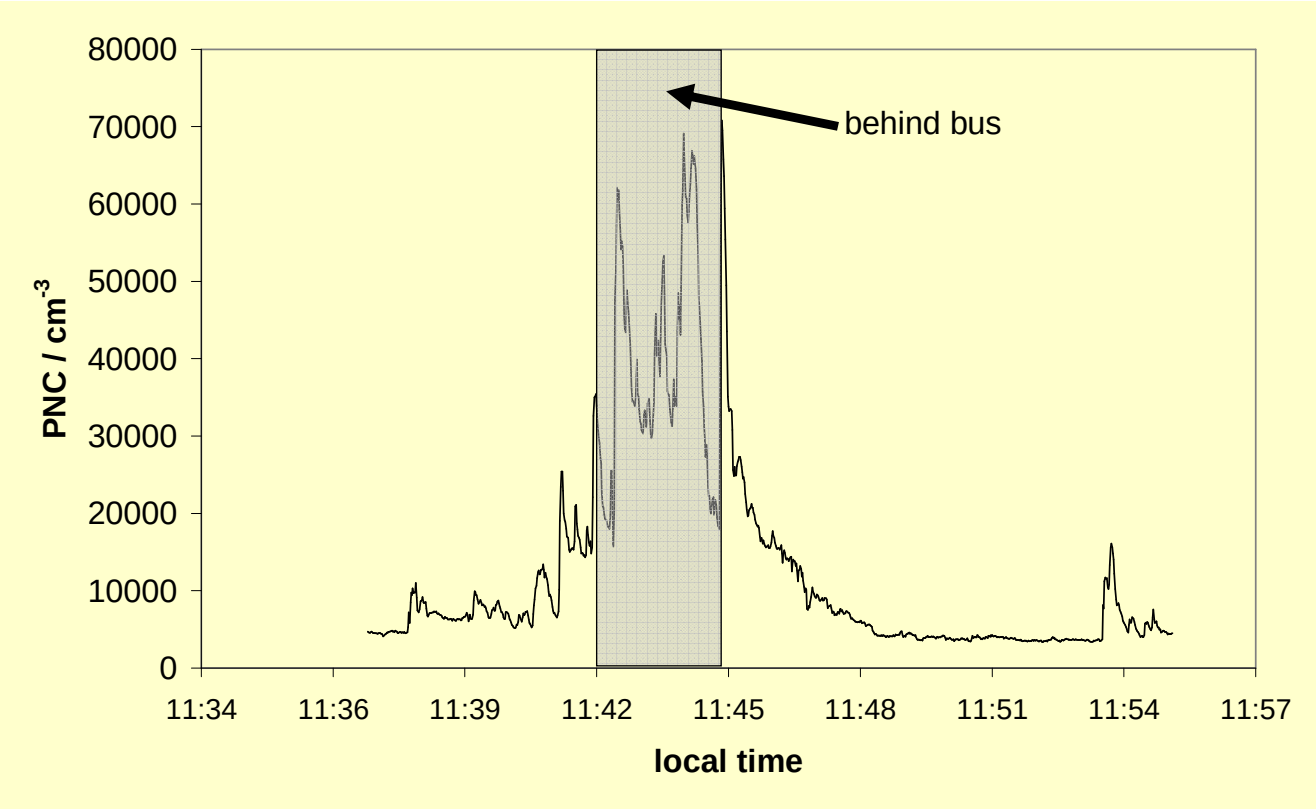


- External concentrations elevated by order of magnitude for 18 seconds
- Internal concentrations elevated 7x (initially), and remain >external for 4 minutes/3.5 km

Landcare Research Manaaki Whenua | Environet ltd Air Quality & IT Specialists | UC University of Canterbury Te Whare Wānanga o Waitaha Christchurch New Zealand | Golder Associates | NIWA Taihoro Nukurangi

Observing and modelling particle number concentrations inside vehicles in busy traffic

Observational features #2: encounters with gross emitters



- 3 minutes behind bus doubled journey mean external PNC

Landcare Research Manaaki Whenua | Environet ltd Air Quality & IT Specialists | UC University of Canterbury Te Whare Wānanga o Waitaha Christchurch New Zealand | Golder Associates | NIWA Taihoro Nukurangi

Observing and modelling particle number concentrations inside vehicles in busy traffic

Experimental determination of air exchange rate

Landcare Research Manaaki Whenua

Environet ltd Air Quality & IT Specialists

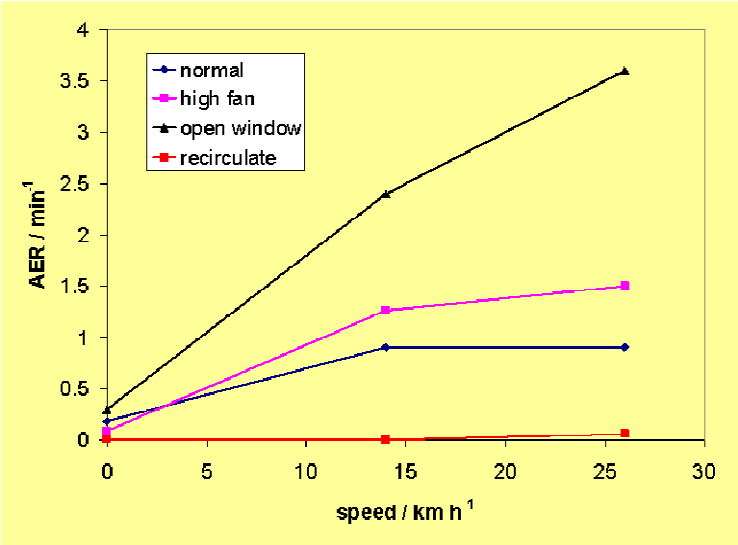
UC UNIVERSITY OF CANTERBURY Te Whare Wānanga o Waitaha CHRISTCHURCH NEW ZEALAND

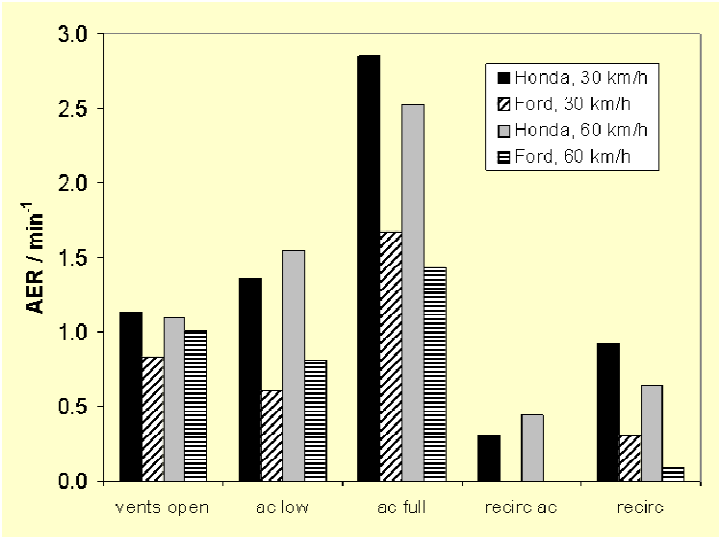
Golder Associates

NIWA Taihoro Nukurangi

Observing and modelling particle number concentrations inside vehicles in busy traffic

Experimental determination of AER





1st-order infiltration model: $\lambda = AV + B = (dNi/dt)/-\Delta N$

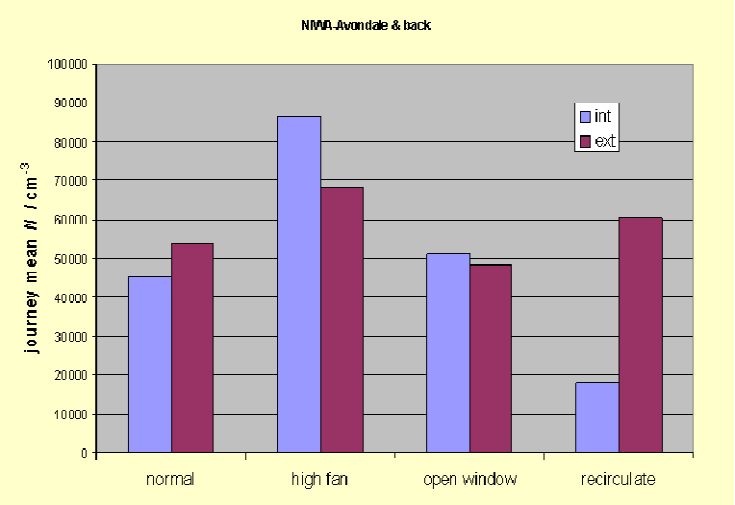
V = speed, and A and B are empirically derived constants describing "leakiness" of the vehicle

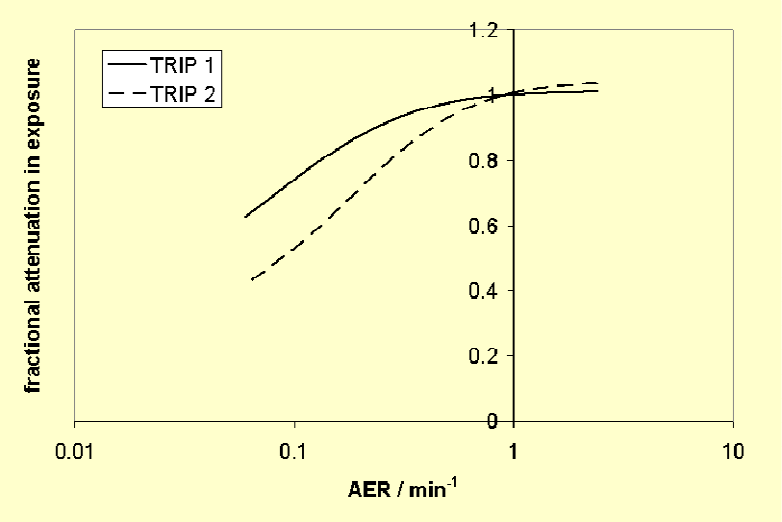
For typical conditions $\lambda \sim 1\ \text{min}^{-1}$

Landcare Research Manaaki Whenua | Environet ltd Air Quality & IT Specialists | UC University of Canterbury Te Whare Wānanga o Waitaha Christchurch New Zealand | Golder Associates | NIWA Taihoro Nukurangi

Observing and modelling particle number concentrations inside vehicles in busy traffic

Initial trial: effect of ventilation settings on journey means





- Reduction in AER has non-linear effect on exposure
- Effect depends on characteristics of the trip (traffic encounters/fresh particle injection events)
- Some evidence of I/O >1 for certain trip/ventilation profiles

Landcare Research Manaaki Whenua | Environet ltd Air Quality & IT Specialists | UC University of Canterbury Te Whare Wānanga o Waitaha Christchurch New Zealand | Golder Associates | NIWA Taihoro Nukurangi

Observing and modelling particle number concentrations inside vehicles in busy traffic

Air exchange modelling

Landcare Research Manaaki Whenua

Environet ltd Air Quality & IT Specialists

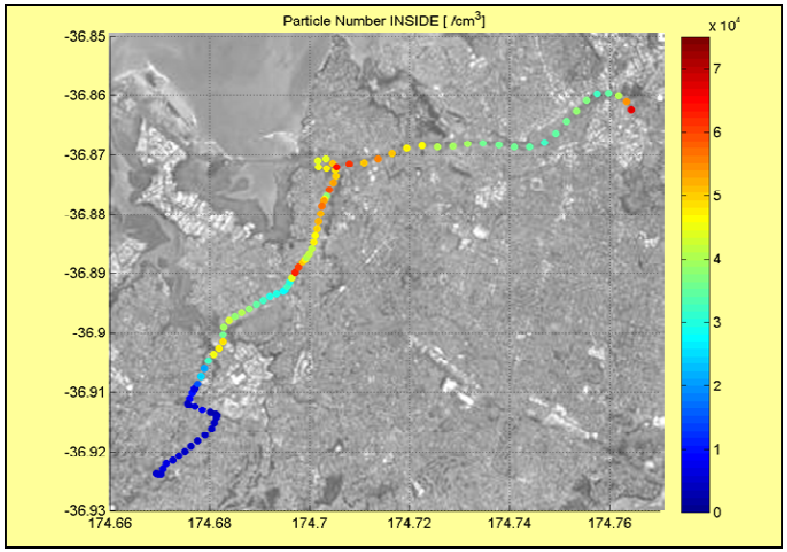
UC University of Canterbury Te Whare Wānanga o Waitaha Christchurch New Zealand

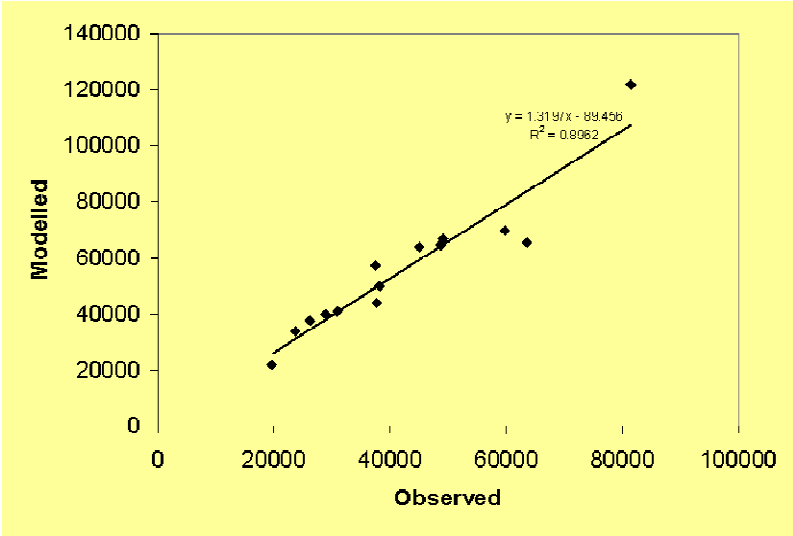
Golder Associates

NIWA Taihoro Nukurangi

Observing and modelling particle number concentrations inside vehicles in busy traffic

Air & Particles Exchange Model (APEX)





Model interior time series based on exterior and speed

Interior obs used as validation only (no feedback into model)

APEX v.1: 1st-order infiltration model: $dNi/dt = -\lambda \Delta N$, where $\lambda = f(V)$

Landcare Research Manaaki Whenua

Environet ltd Air Quality & IT Specialists

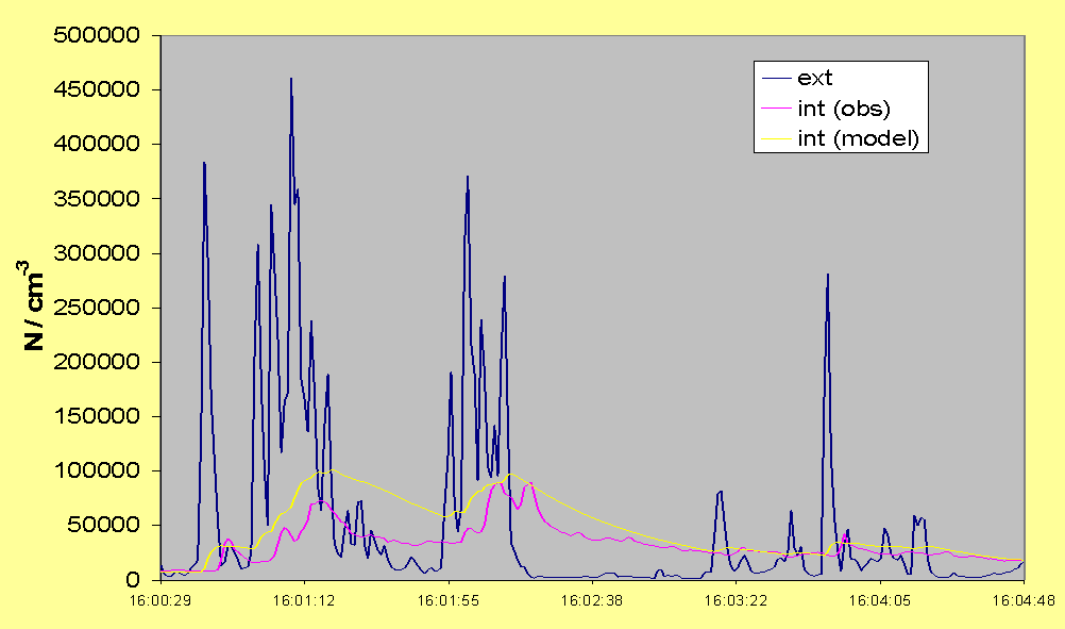
UC UNIVERSITY OF CANTERBURY Te Whare Wānanga o Waitaha CHRISTCHURCH NEW ZEALAND

Golder Associates

NIWA Taihoro Nukurangi

Observing and modelling particle number concentrations inside vehicles in busy traffic

v.1 Model weaknesses

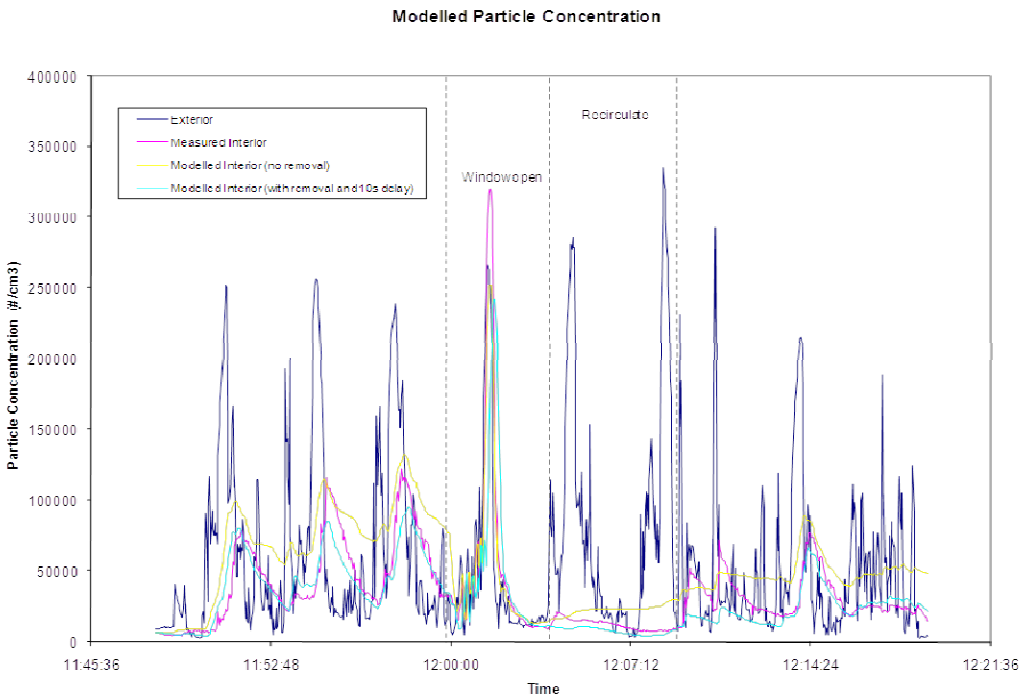


- Model missing lag in internal response
- Model under-representing initial rapid decay post-injection (when PNC:PM_{10} ratio was elevated – not shown)
- Interpretation: increased removal of UFP during high concentrations (gross-emitter encounter?) or within first ~20 seconds after injection

Landcare Research Manaaki Whenua | Environet ltd Air Quality & IT Specialists | UC University of Canterbury Te Whare Wānanga o Waitaha Christchurch New Zealand | Golder Associates | NIWA Taihoro Nukurangi

Observing and modelling particle number concentrations inside vehicles in busy traffic

Terrace Tunnel model initialisation



- Trialled adding simple removal (deposition) and lag (mixing) terms
- Initialised on data from drive-throughs of Terrace Tunnel (Wellington)
- Lag based on CO data, removal based on PNC (Ptrak) data

Landcare Research Manaaki Whenua | Environet ltd Air Quality & IT Specialists | UC University of Canterbury Te Whare Wānanga o Waitaha Christchurch New Zealand | Golder Associates | NIWA Taihoro Nukurangi

Observing and modelling particle number concentrations inside vehicles in busy traffic

Remaining weaknesses of model (v.3)

$$\frac{dN(t)}{dt} = \left(Av(t) + B\right)\left(N_{out}\left(t - t_{lag}\right) - N(t)\right) - kN(t)$$

- Lag term (t_{lag} = 10 s) is arbitrary
- Particle deposition term (k = 0.009 s^{-1}) should be particle size-dependent
- Currently based on data from Ptrak with uncertain response < 50 nm

Landcare Research Manaaki Whenua | Environet ltd Air Quality & IT Specialists | UC University of Canterbury Te Whare Wānanga o Waitaha Christchurch New Zealand | Golder Associates | NIWA Taihoro Nukurangi

Observing and modelling particle number concentrations inside vehicles in busy traffic

Where next for the modelling?

Air exchange modelling:

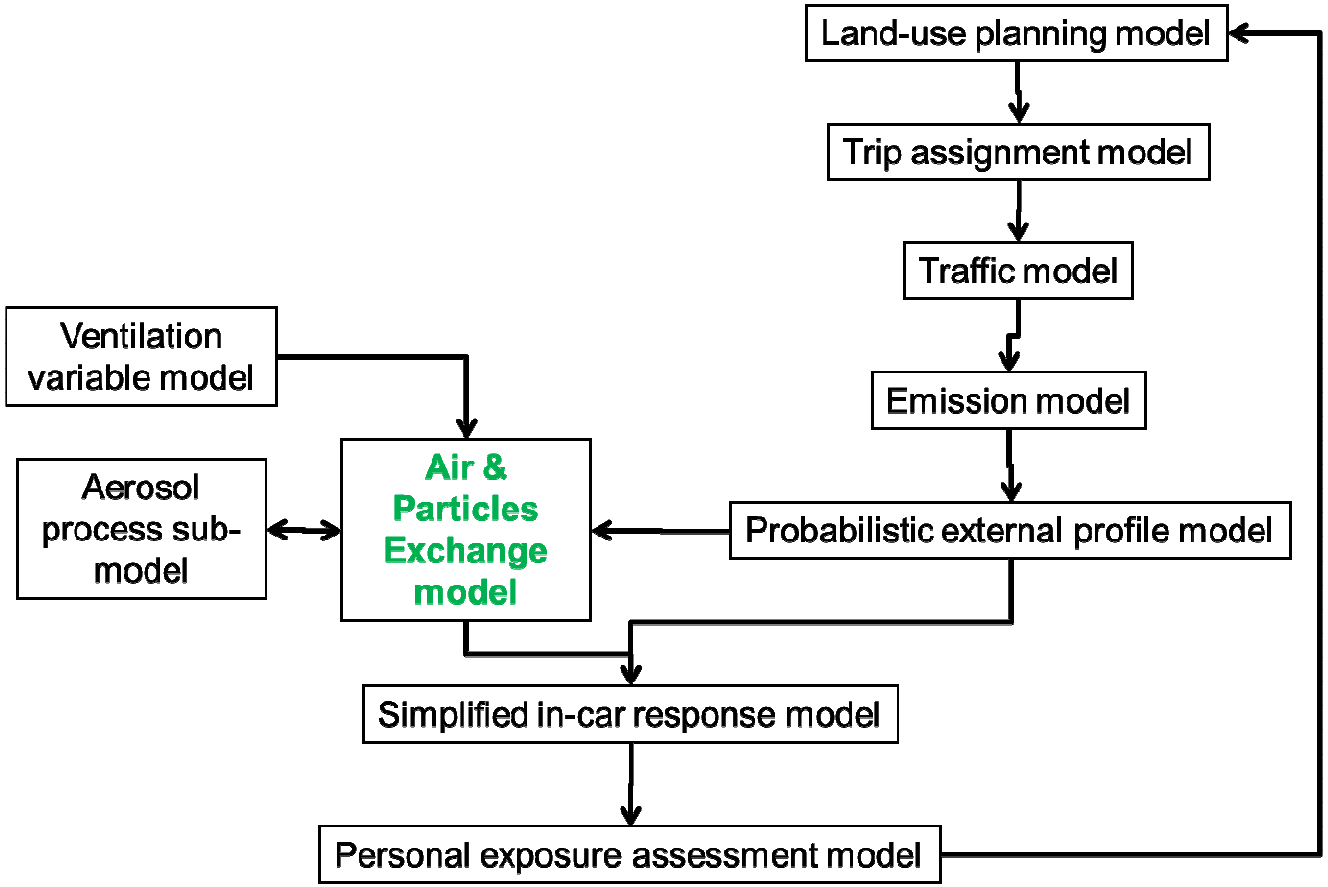
- Size-dependent processes (SMPS?)
- More complex process modelling
- Intercomparison with simpler “black box” (e.g. band-pass filter) modelling

Operational modelling:

- Relate statistical properties of external concentrations to traffic data and emissions modelling
- Developing probabilistic modelling for population in-transit exposure

Landcare Research Manaaki Whenua | Environet ltd Air Quality & IT Specialists | UC University of Canterbury Te Whare Wānanga o Waitaha Christchurch New Zealand | Golder Associates | NIWA Taihoro Nukurangi

Proposed model integration



Landcare Research Manaaki Whenua

Environet ltd Air Quality & IT Specialists

UC University of Canterbury Te Whare Wānanga o Waitaha Christchurch New Zealand

Golder Associates

NIWA Taihoro Nukurangi

Thanks for your attention

This research was funded by

NIWA
New Zealand Transport Agency
Foundation for Research, Science & Technology

Kind thanks to Auckland Regional Council for loan of one of the P-Traks

Landcare Research Manaaki Whenua

Environet ltd Air Quality & IT Specialists

UC UNIVERSITY OF CANTERBURY Te Whare Wānanga o Waitaha CHRISTCHURCH NEW ZEALAND

Golder Associates

NIWA Taihoro Nukurangi