Source apportionment of airborne particles in the Auckland region

Photo from MetVuw: Henderson Valley by Diarmuid Kingsleigh-Smith, 07:25 18 May 2007

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Outline

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2. Elements and their concentrations
3. Data analysis and quality assurance
4. Source apportionment
5. Identification of predominant sources
6. Temporal and seasonal variations
7. High pollution days
8. ‘One off’ local sources
9. Source strength and wind direction
10. Intersite comparison of sources
11. Regional sources
12. Receptor modelling versus emissions inventory
13. Some key conclusions

Introduction – Sites and Samples

5 sites and 10 samples sets of particulate matter from across the Auckland region:

- Takapuna – 110 PM_{10}
- Khyber Pass, Newmarket – 115 $PM_{2.5}$ and PM_{10}
- Queen St, Auckland – 110 $PM_{2.5}$ and 305 PM_{10}
- Gavin St, Penrose – 90 $PM_{2.5}$ and 75 PM_{10}
- Kowhai Intermediate, Kingsland – 237 speciated $PM_{2.5}$, 114 $PM_{2.5}$ and 115 PM_{10}

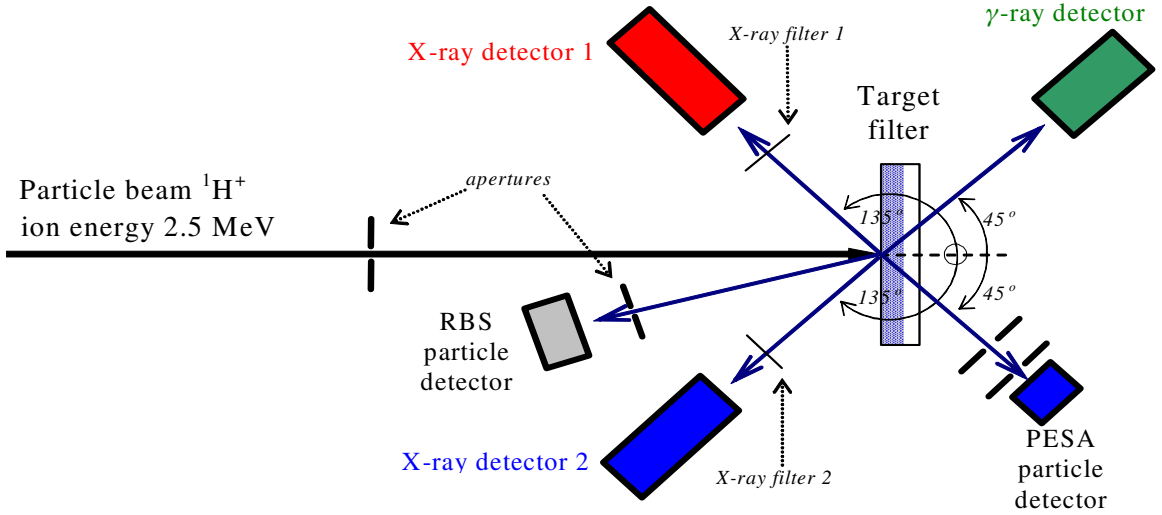
This is the most extensive study of its kind to date in NZ

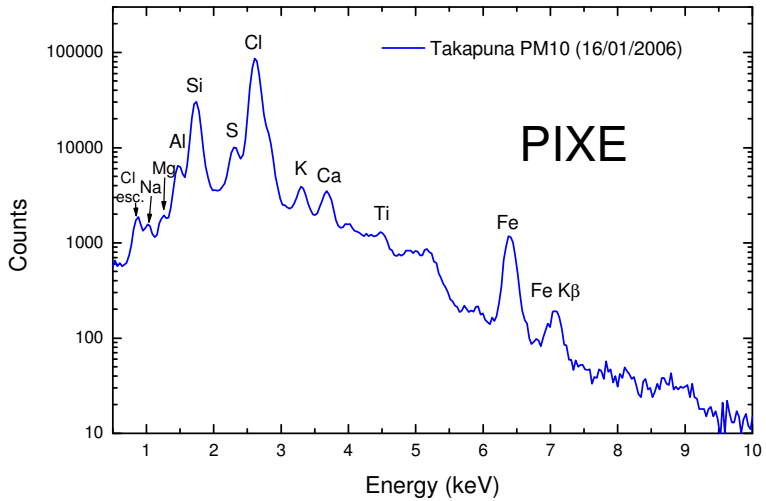
Introduction - Some definitions:

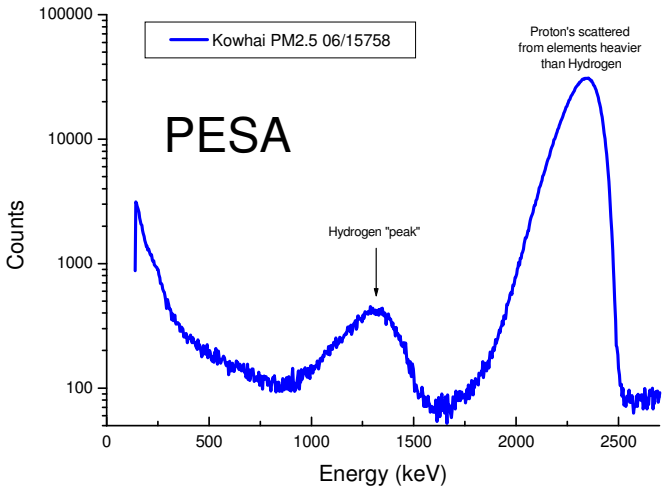
- APM – air particulate matter
- Biomass burning – combustion of plant material, wood
- Marine aerosol – seasalt
- Crustal matter - soil
- Secondary particles –formed in the atmosphere from precursor particles, gases or liquid droplets as a result of atmospheric chemistry e.g. secondary sulphate particles from SO_2 gas
- Coarse and fine particles – refers to $PM_{10-2.5}$ and $PM_{2.5}$ respectively

Elements and their concentrations

…are measured at the New Zealand ion beam analysis facility at Gracefield, Lower Hutt







Analysis of $PM_{2.5}$ and PM_{10} datasets

Typical elements and their LODs

Element	Method	Limits of detection
H	PESA	500 ppm – 1000 ppm
Na	PIGE	500 ppm - 1000 ppm
Mg	PIXE K line	10 ppm - 100 ppm
Al…Sr	PIXE K line	10 ppm - 100 ppm
Sr…U	PIXE L line	50 ppm - 300 ppm
Sm…U	PIXE M line	100 ppm - 500 ppm

C, N, O measured by RBS for QA/QC

BC measured by light reflectance

Quality assurance of datasets:

- QA involves removal of samples with damaged filters, no reported / no gravimetric mass
- Time series plots of analytes
- Scatterplots of one analyte vs another to examine relationships
- Mass reconstruction and comparison with gravimetric mass

Source Apportionment

- Three main methods of source apportionment: emissions inventories, dispersion modelling and receptor modelling
- Emissions inventories and dispersion modelling use source activity to predict ambient contributions whereas receptor modelling uses ambient concentrations to infer source contributions
- A key advantage of receptor modelling is the ability to determine mass contributions to APM from sources that are difficult to quantify source activity
- A combination of approaches may be most effective in providing the ‘weight of evidence’ and utility for air quality management and policy formulation

General conceptual receptor model for Auckland

Local emission sources:

- Domestic activities – likely to be dominated by biomass burning
- Motor vehicles – all roads in area act as line sources and roads with higher density traffic will dominate PM profile
- Local wind blown soil or road dust sources
- Industrial emissions

Longer range sources:

- Marine aerosol (seasalt)
- Secondary sources (sulphate, nitrate, SOA)
- Potential for industrial emissions?
- Australian dust, fires
- Global background

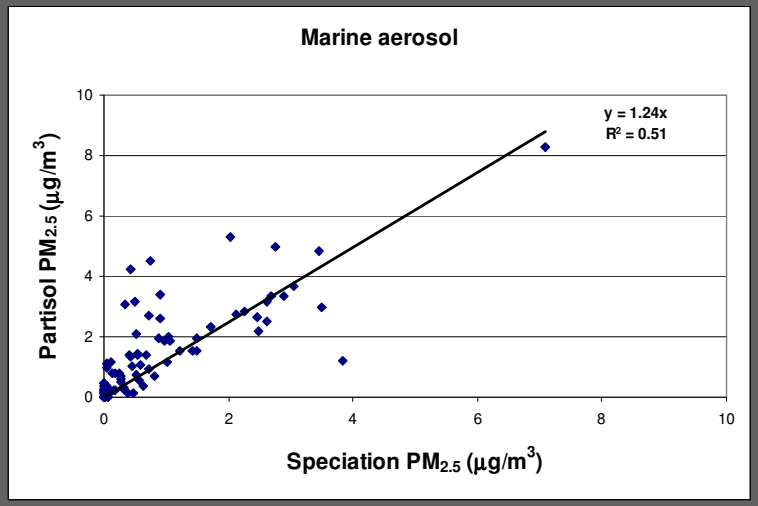
'One-off' emissions sources:

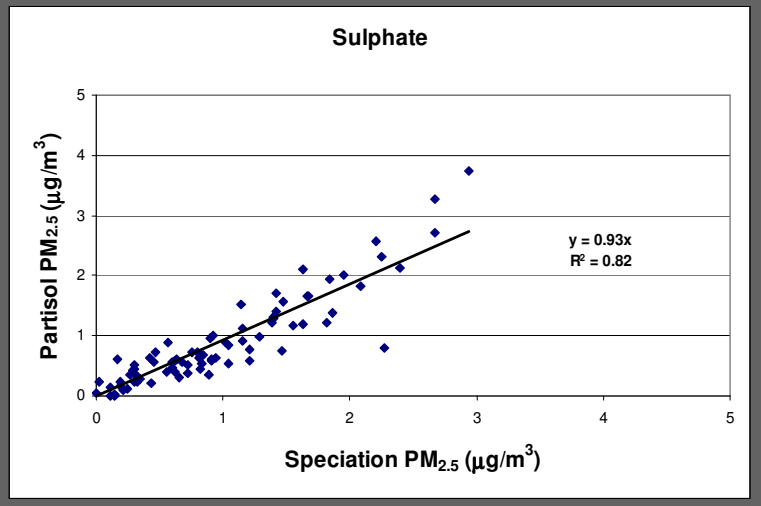
- Fireworks displays
- Short-term road works or construction activities
- Others?

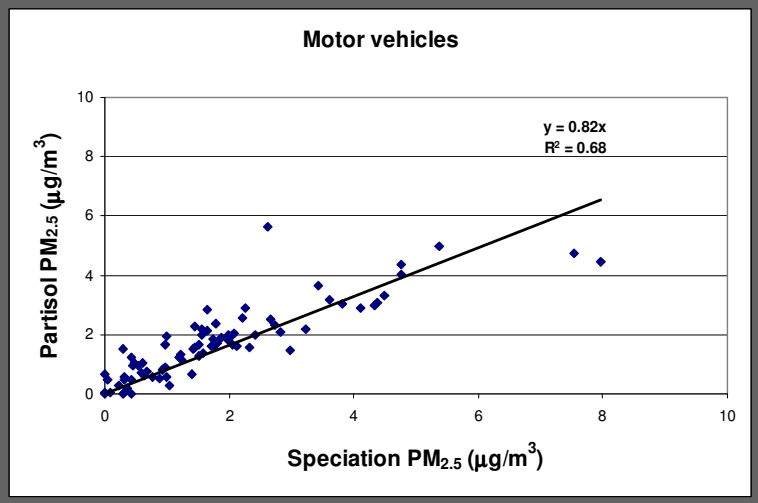
Source apportionment of $PM_{2.5}$ and PM_{10} mass – this is what we do when we assemble the data

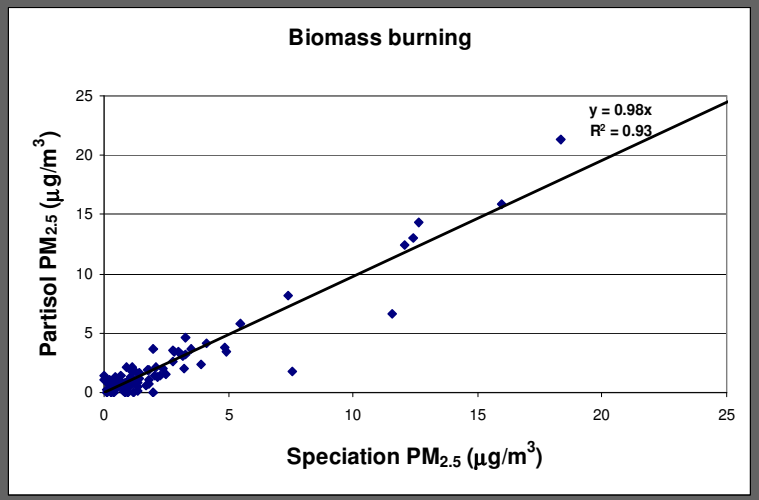
- Principal components analysis used to estimate number of factors (sources) that may be present
- Further factor analysis and source mass contributions by positive matrix factorisation
- Process is reiterative to achieve a meaningful and defensible outcome
- Solutions must be backed up by analysis of meteorological factors and continuous PM_{10} monitoring results

Receptor modelling…it works!
Intrasite comparison – Kingsland $PM_{2.5}$ sources

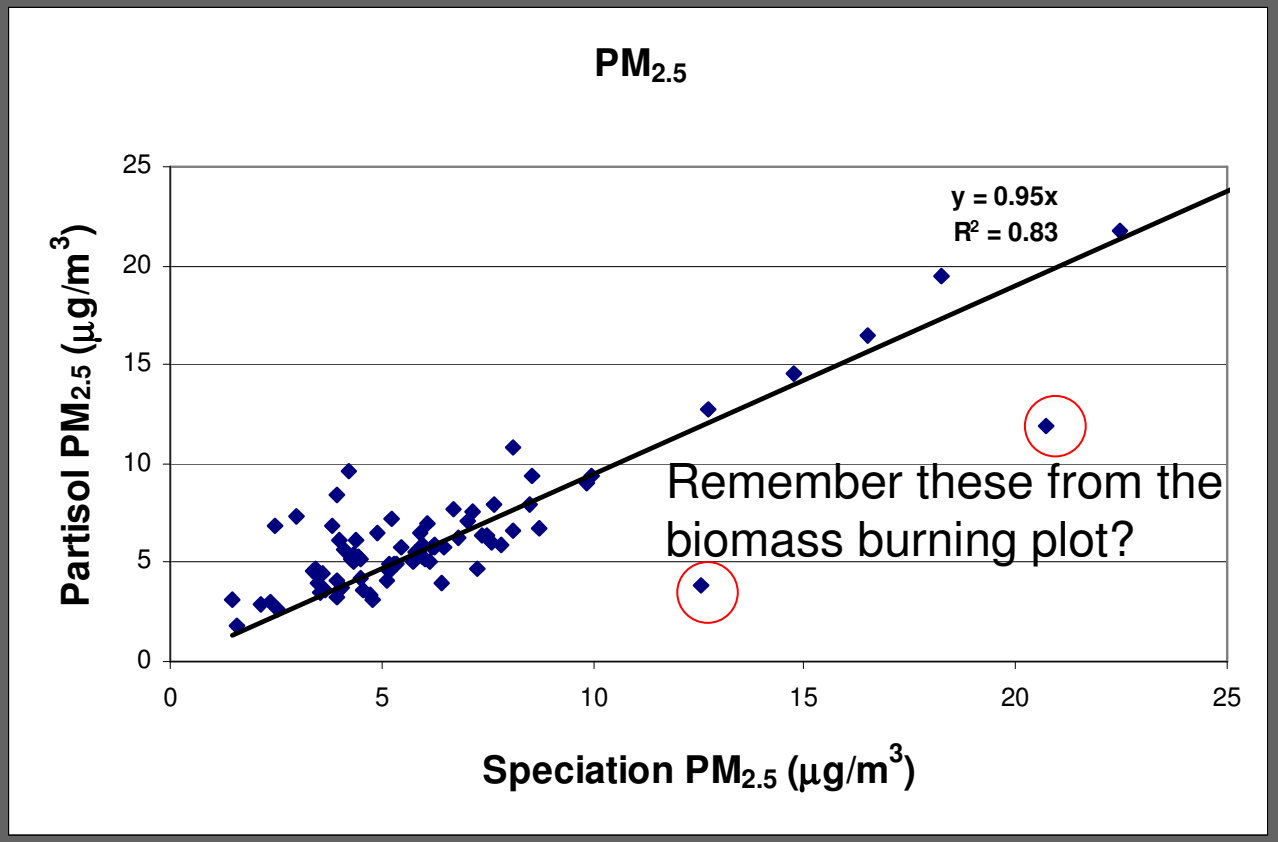






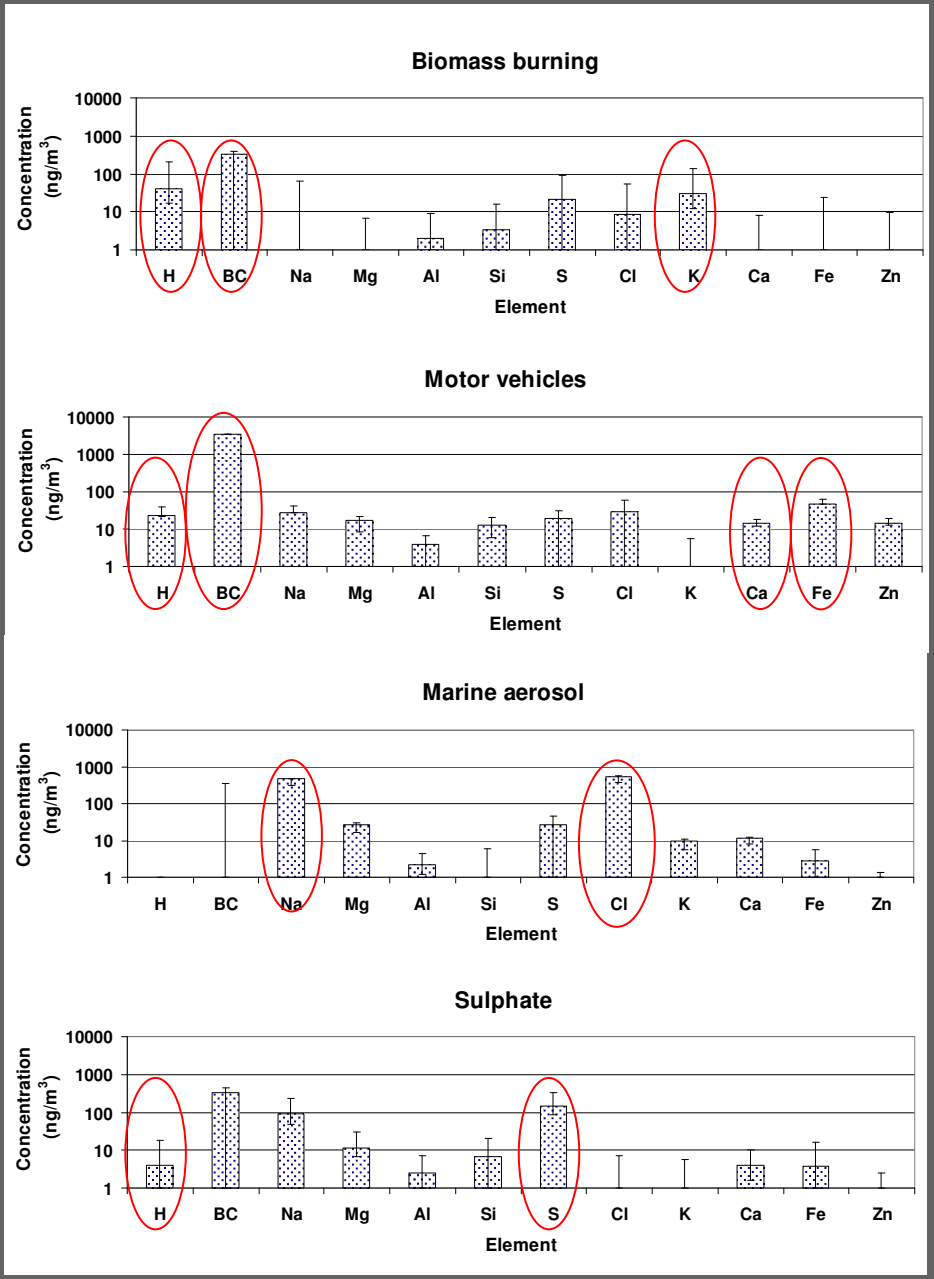


Intrasite comparison – Kingsland $PM_{2.5}$ mass

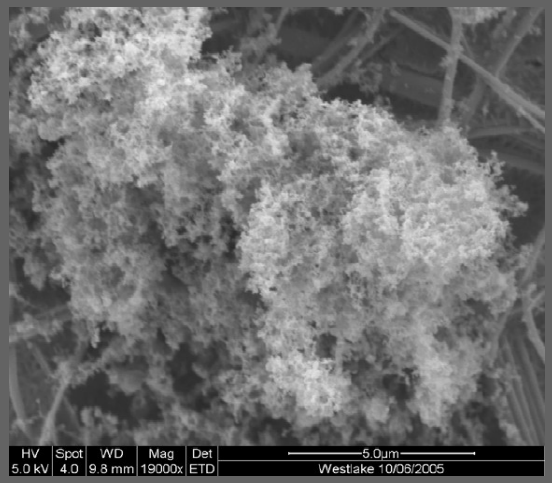


Source profiles

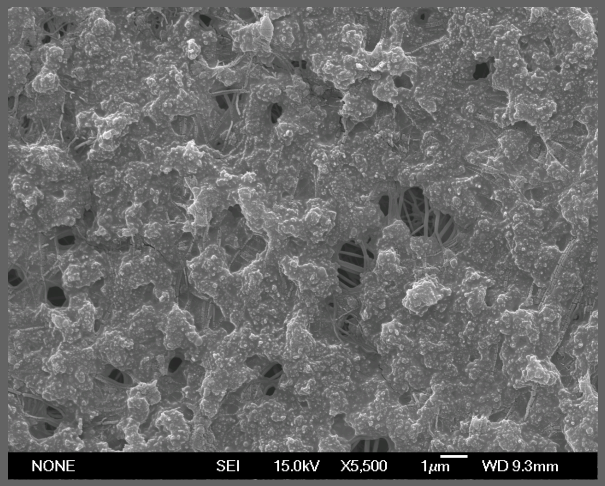
- Source profiles are derived from the statistical associations between constituent elements for ambient APM or from direct measurement of emission sources
- In theory ambient profiles should resemble measured source profiles, but we need to keep in mind atmospheric chemistry (e.g. secondary particulate matter sources)



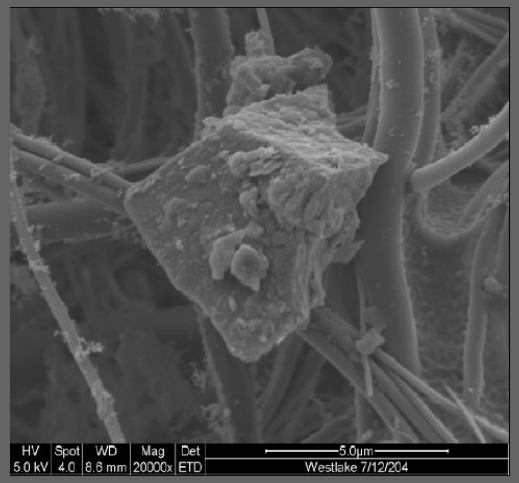
So what do some of these particles look like?



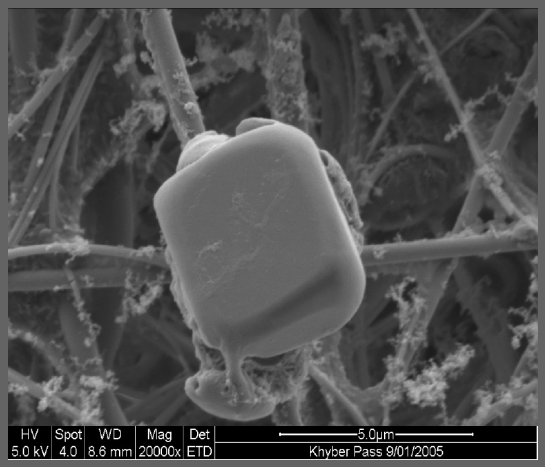
Combustion



Combustion – wood burner

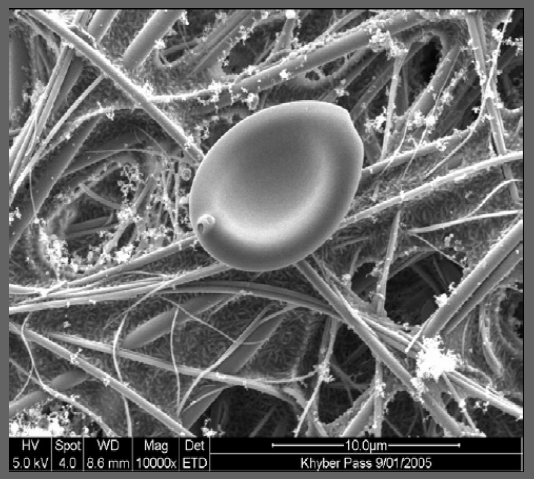


Crustal matter

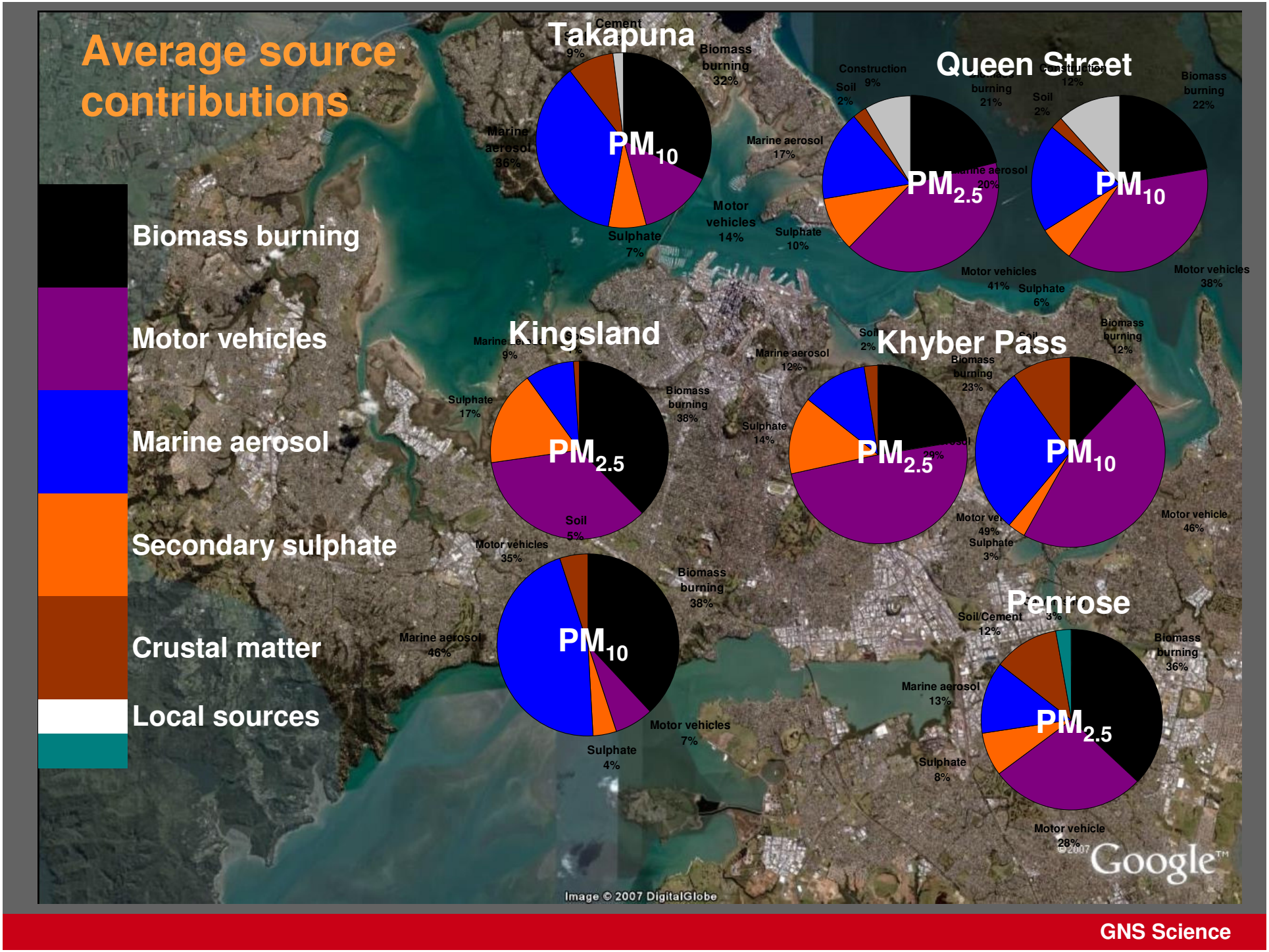


Sea salt

Glass shard



Fungal spore


Average source contributions
Biomass burning
Motor vehicles
Marine aerosol
Secondary sulphate
Crustal matter
Local sources
Takapuna
PM10
Cement 9%
Biomass burning 32%
Marine aerosol 36%
Sulphate 7%
Motor vehicles 14%
Sulphate 10%
Queen Street
PM2.5
Construction 9%
Soil 2%
Biomass burning 21%
Marine aerosol 17%
Marine aerosol 20%
Motor vehicles 41%
Sulphate 6%
PM10
Soil 2%
Biomass burning 22%
Motor vehicles 38%
Kingsland
PM2.5
Marine aerosol 9%
Sulphate 17%
Biomass burning 38%
Soil 5%
PM10
Motor vehicles 35%
Biomass burning 38%
Marine aerosol 46%
Sulphate 4%
Motor vehicles 7%
Khyber Pass
PM2.5
Marine aerosol 12%
Biomass burning 23%
Sulphate 14%
PM10
Biomass burning 12%
Motor vehicle 46%
Motor ve 49%
Sulphate 3%
Penrose
PM2.5
Soil/Cement 12%
Biomass burning 36%
Marine aerosol 13%
Sulphate 8%
Motor vehicle 28%
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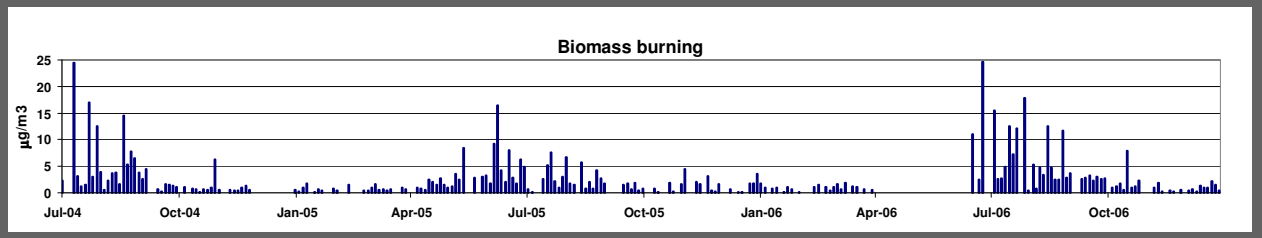
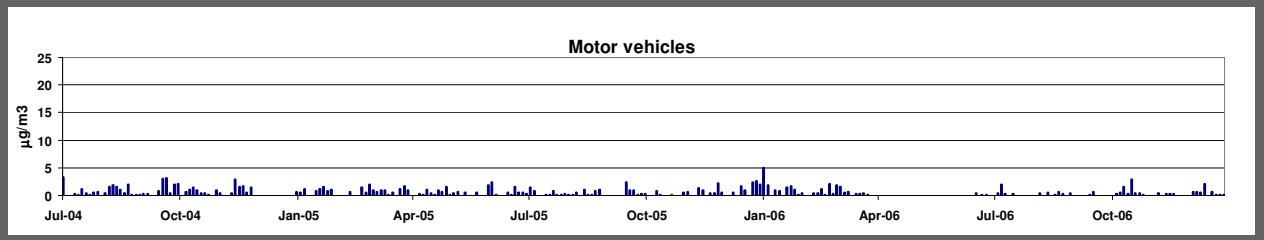
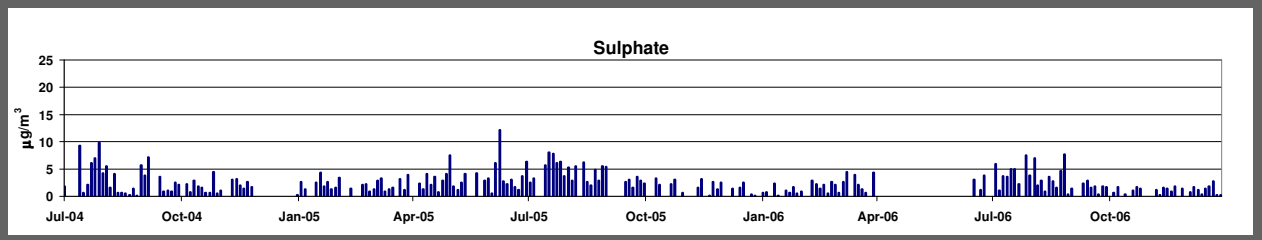
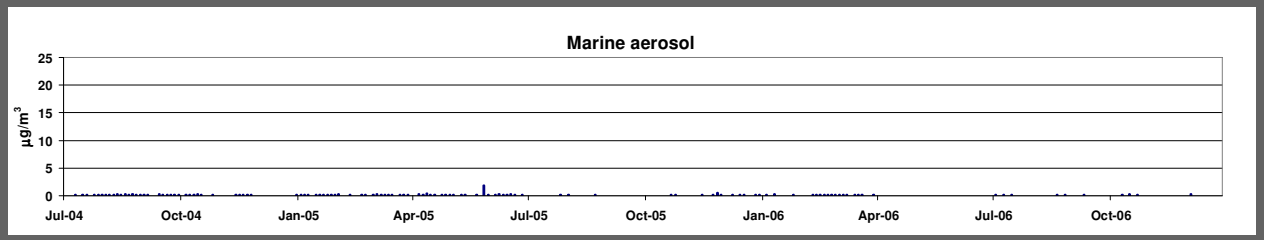
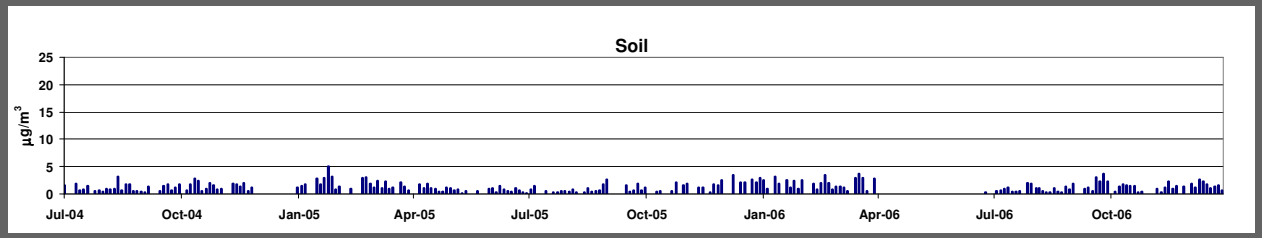
Temporal variation – Kingsland $PM_{2.5}$ (2004 - 2006)



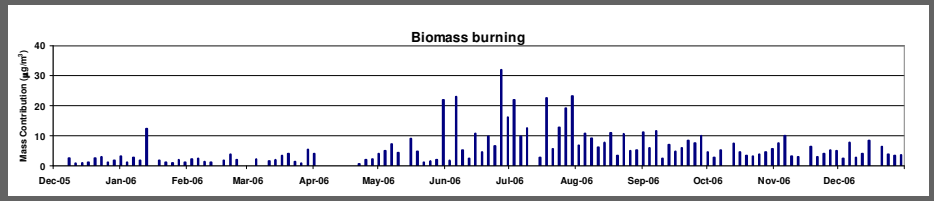


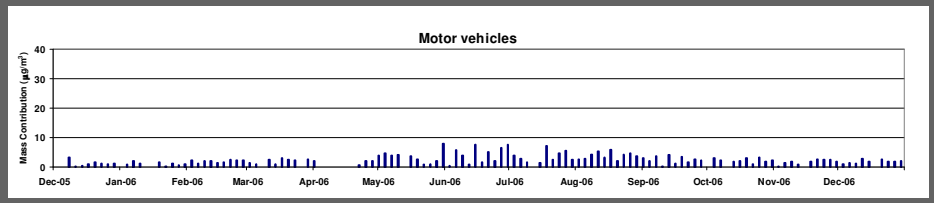


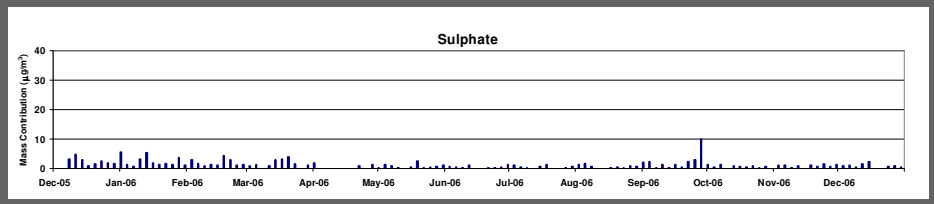


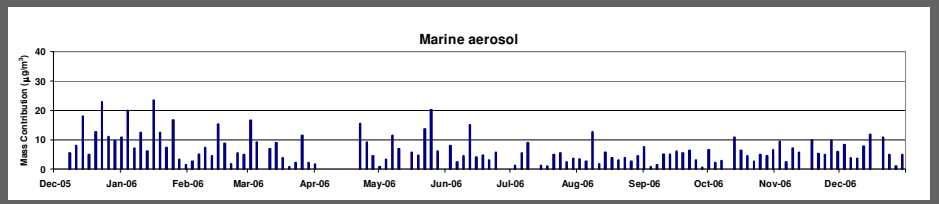


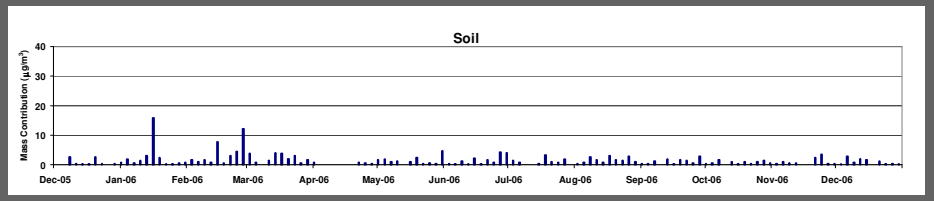
Temporal variation – Takapuna PM_{10} (2006)

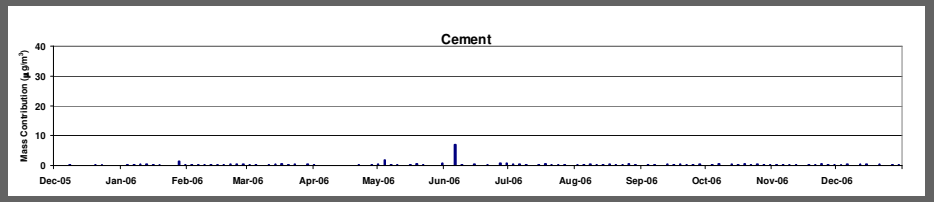


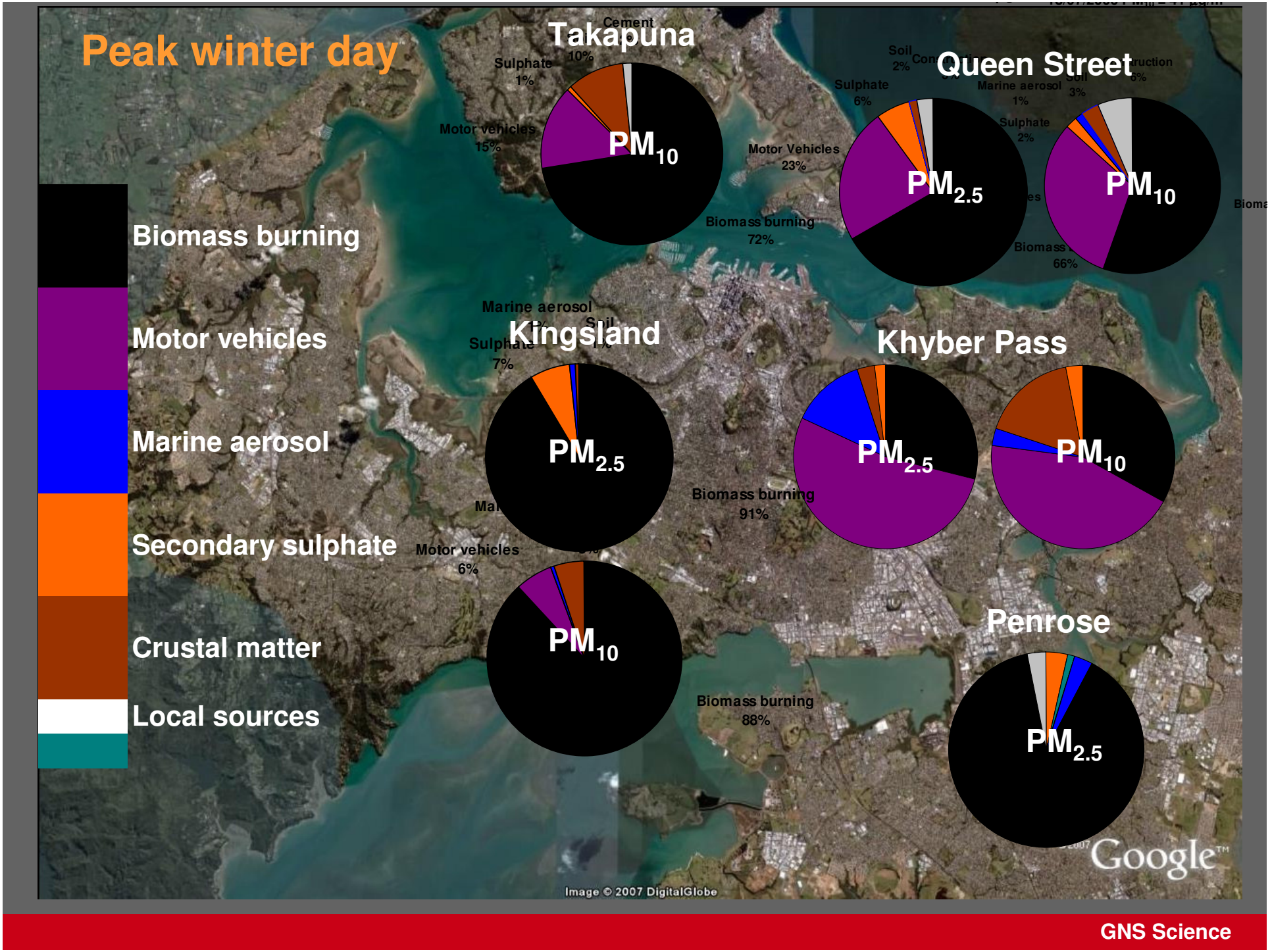











Peak winter day
Takapuna
Cement 10%
Sulphate 1%
Motor vehicles 15%
Biomass burning 72%
PM10
Queen Street
Soil 2%
Sulphate 6%
Marine aerosol 1%
Sulphate 2%
Motor Vehicles 23%
Biomass burning 66%
PM2.5
PM10
Kingsland
Marine aerosol
Sulphate 7%
Motor vehicles 6%
Biomass burning 88%
PM2.5
PM10
Khyber Pass
Biomass burning 91%
PM2.5
PM10
Penrose
Biomass burning 88%
PM2.5
Biomass burning
Motor vehicles
Marine aerosol
Secondary sulphate
Crustal matter
Local sources
Image © 2007 DigitalGlobe
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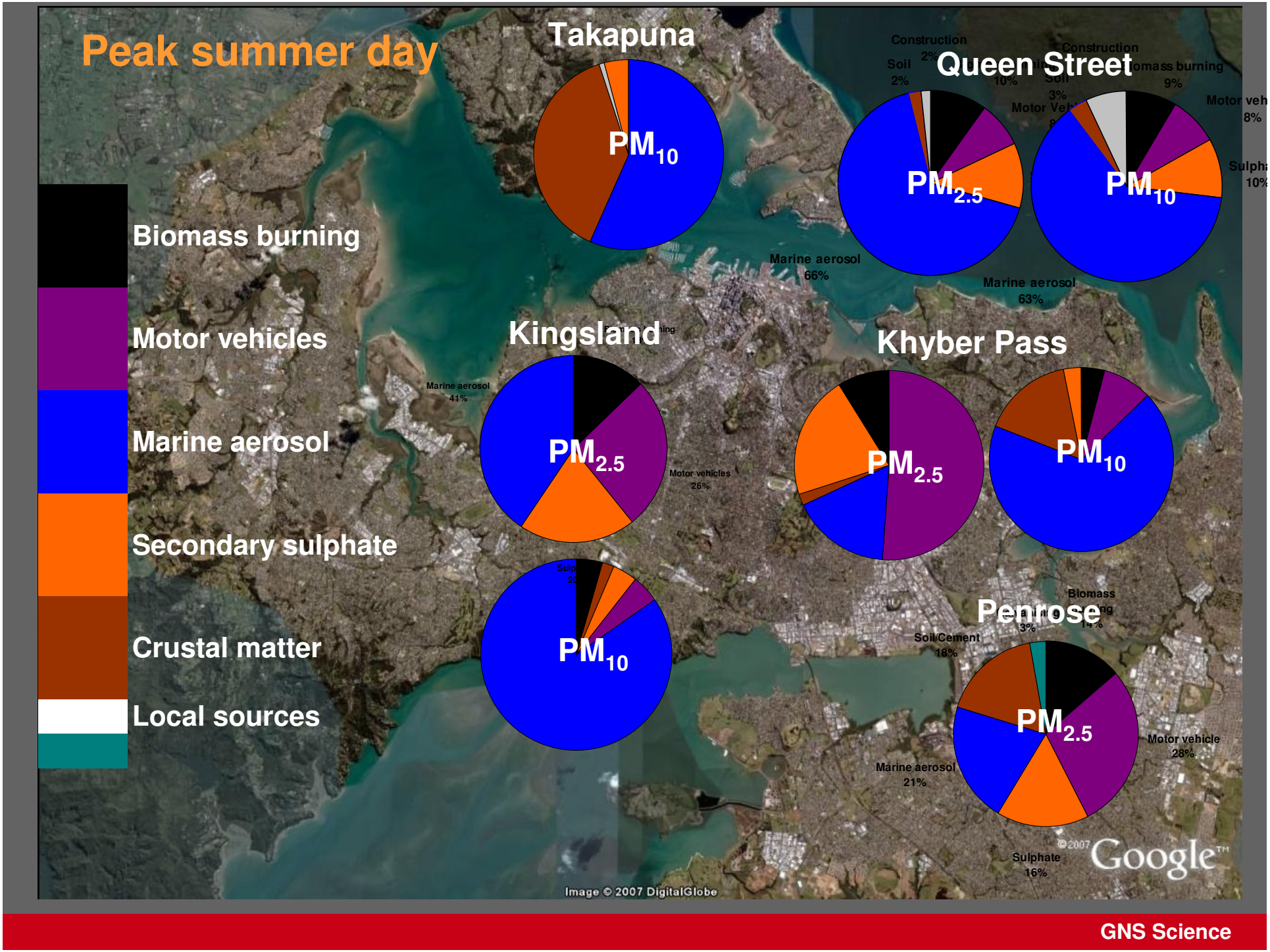
Peak summer day
Takapuna
PM10
Queen Street
Construction
2%
Soil
2%
Construction
10%
Biomass burning
9%
Motor veh
8%
Sulpha
10%
PM2.5
PM10
Marine aerosol
66%
Marine aerosol
63%
Biomass burning
Kingsland
Marine aerosol
41%
PM2.5
Motor vehicles
26%
Khyber Pass
PM2.5
PM10
Sulp
20
PM10
Penrose
Biomass
3%
14%
Soil/Cement
18%
PM2.5
Motor vehicle
28%
Marine aerosol
21%
Sulphate
16%
Biomass burning
Motor vehicles
Marine aerosol
Secondary sulphate
Crustal matter
Local sources
Image © 2007 DigitalGlobe
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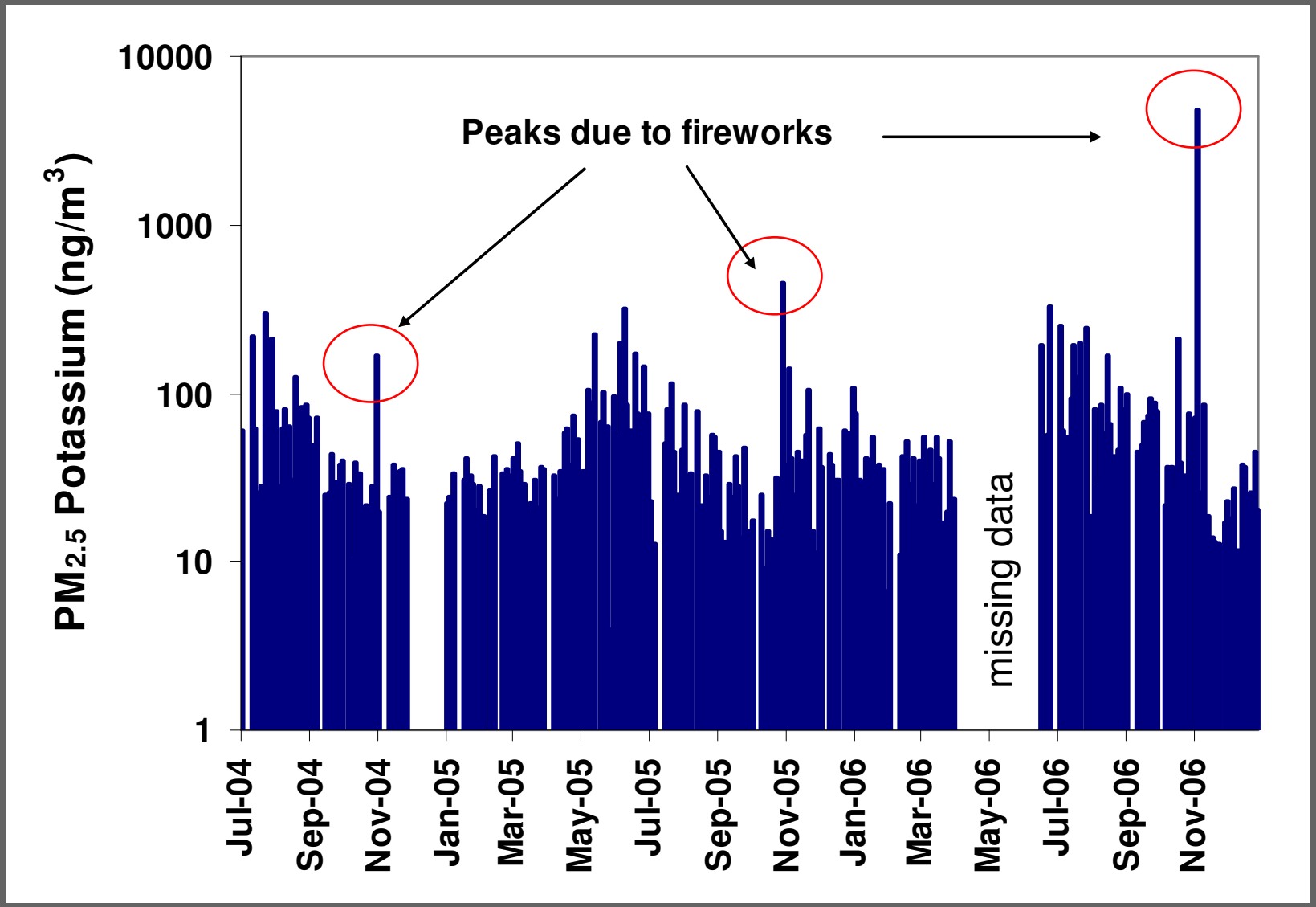
‘One-off’ events - High potassium concentrations as measured at Kingsland (peaks also for Al, Mg, Cu, S)



Source strength and wind direction

- Analysis of source contribution vs wind direction
- Probability that a given factor contribution from a given wind direction will exceed a predetermined threshold criterion (upper 25 % of contribution)

$$CPF_{\Delta\theta} = \frac{m_{\Delta\theta}}{n_{\Delta\theta}}$$

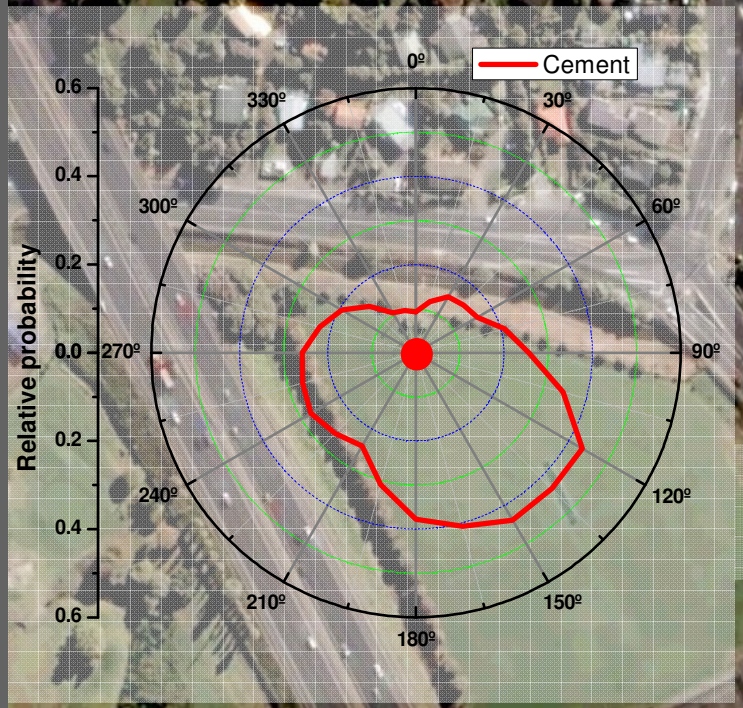
$m_{\Delta\theta}$: number of occurrence from wind sector $\Delta\theta$ that are upper 25 % of source contributions

$n_{\Delta\theta}$: total number of occurrence from the same wind sector

- Sources are likely to be located in the directions that have high CPF values

Directionality of motor vehicle emission source at Kowhai, Kingsland

Directionality of ‘cement’ emission source at Westlake, Takapuna



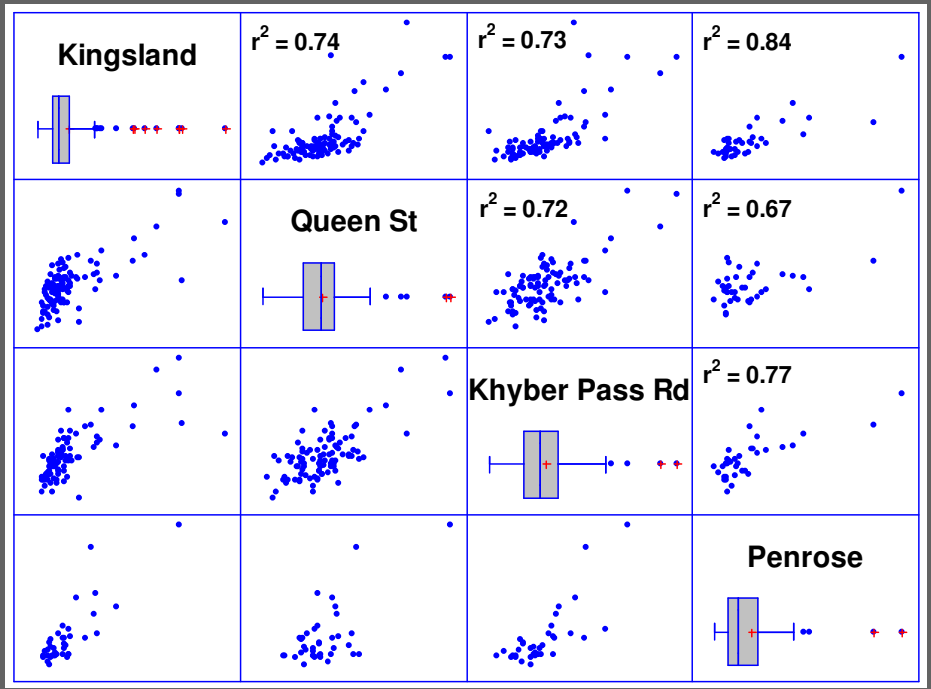
Concrete batching plant

Pointer 36°46'50.61" S 174°45'01.25" E elev 24 m Streaming 100% Eye alt 513 m

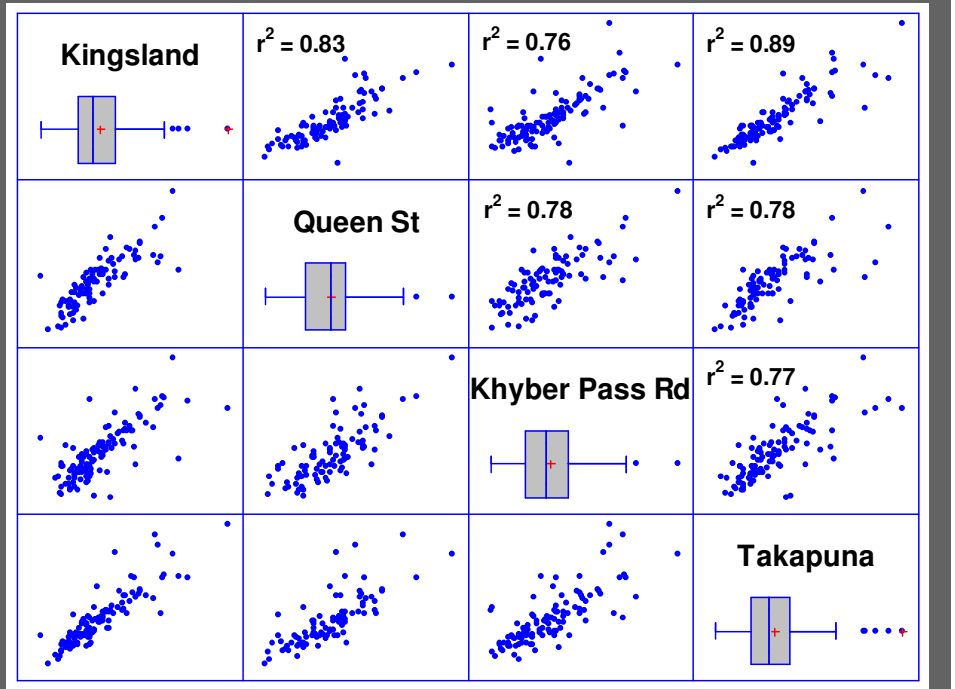
What is the relationship between monitoring sites?

- Intersite correlations better for PM_{10} than $PM_{2.5}$
  - This suggests different drivers (sources) for $PM_{2.5}$ and $PM_{10-2.5}$

$PM_{2.5}$

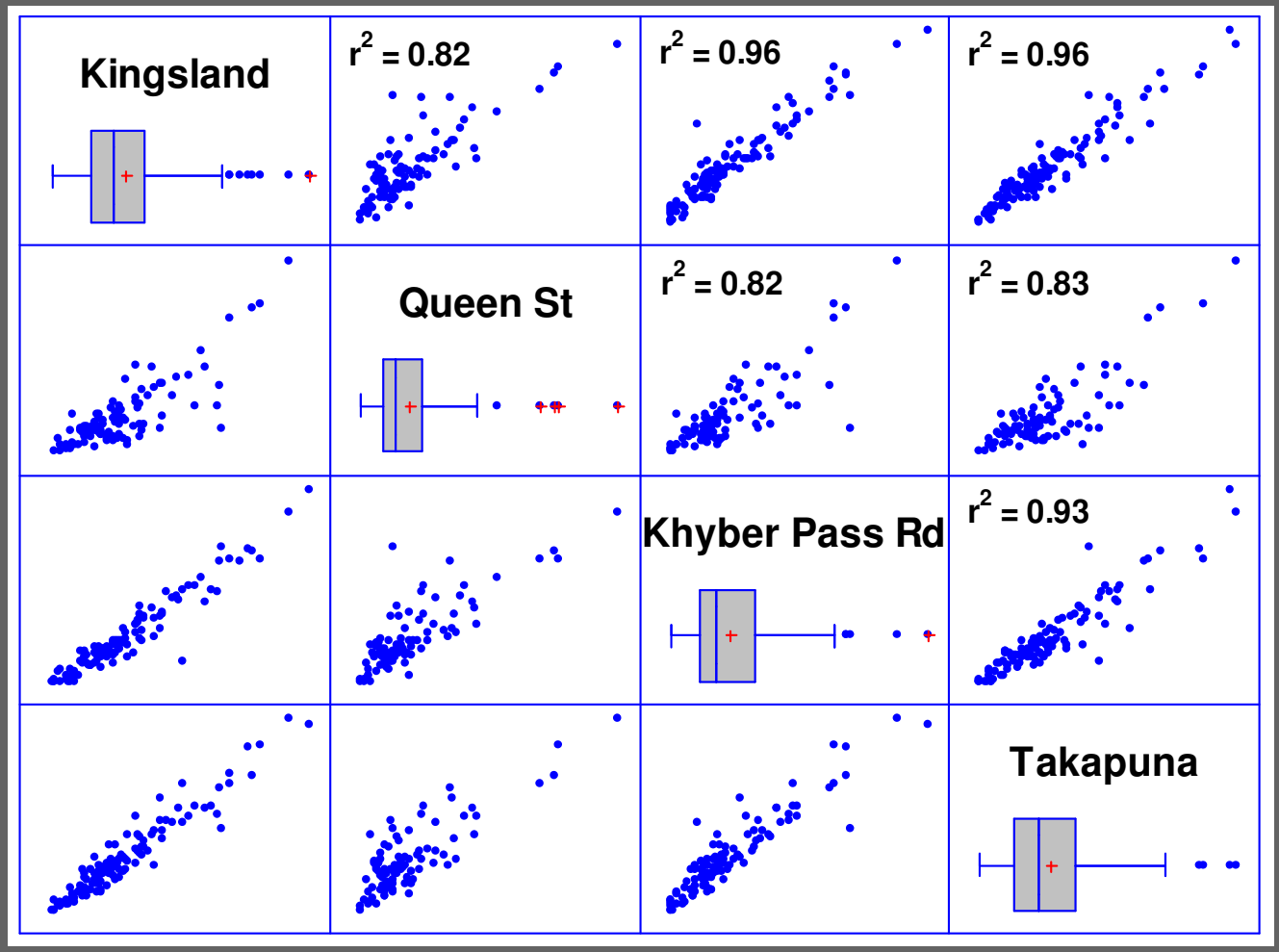


PM_{10}



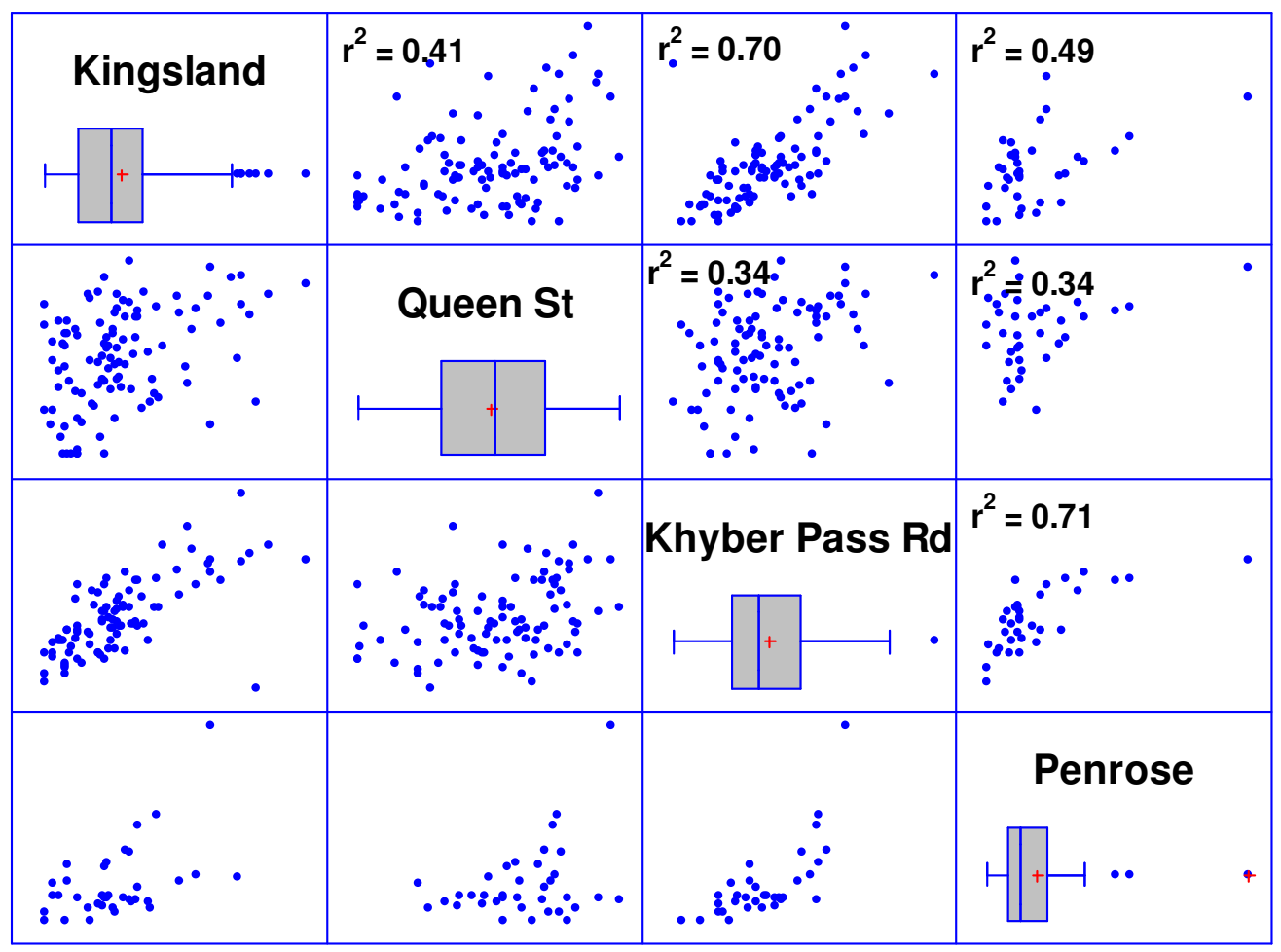
Intersite comparison contd – PM_{10} marine aerosol

- Marine aerosol source well correlated across all sites ⇒ regional source
- Marine aerosol is primarily a $PM_{10-2.5}$ particle source which may explain the better correlation for PM_{10} mass



Intersite comparison contd – $PM_{2.5}$ motor vehicles

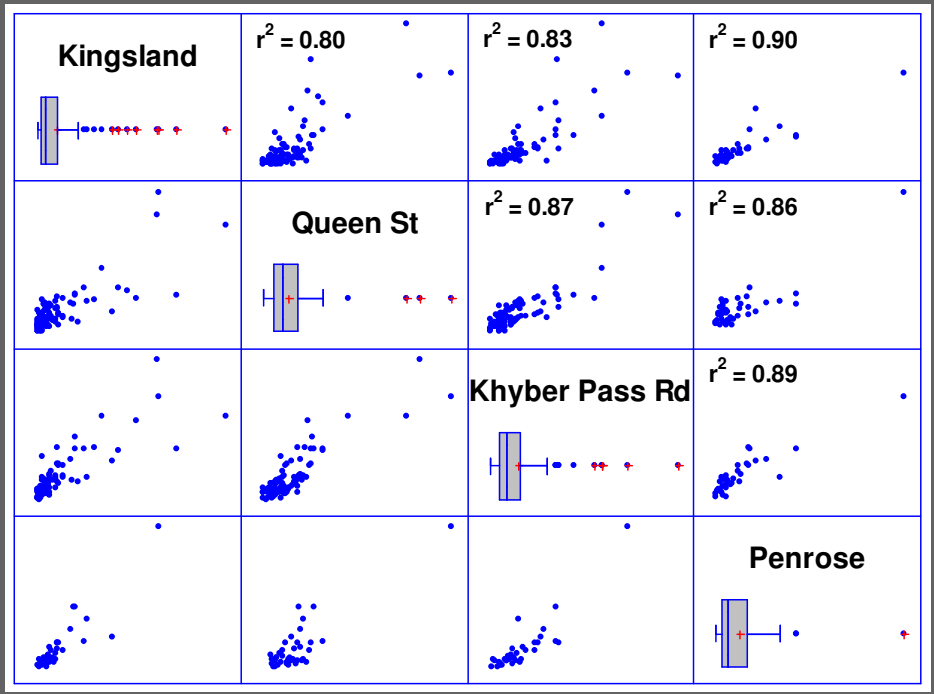
- Motor vehicle sources some are better correlated than others ⇒ local source



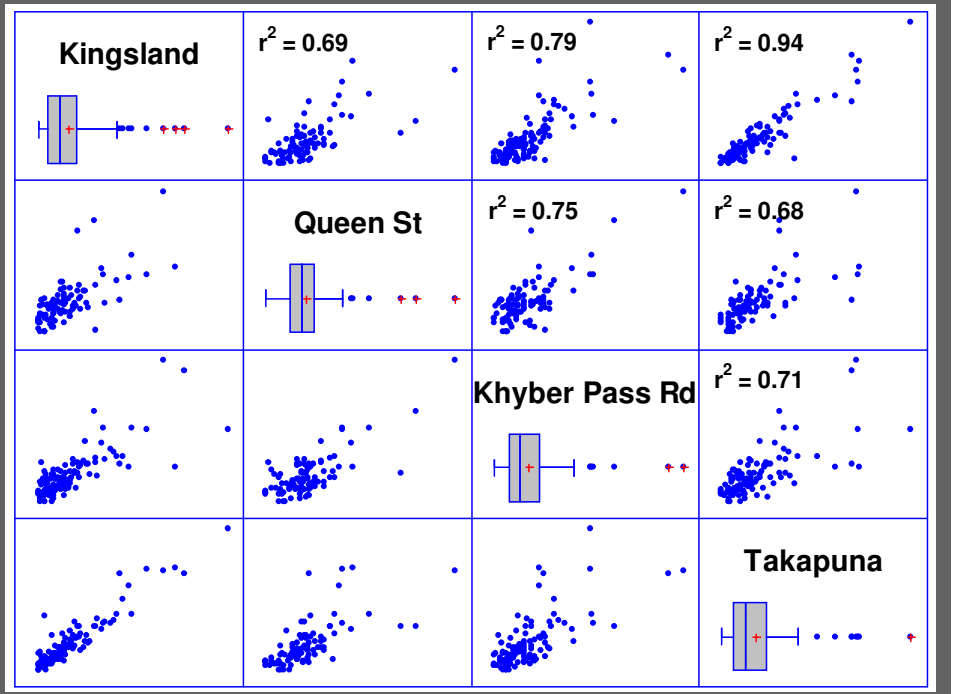
Intersite comparison contd – $PM_{2.5}$ and PM_{10} biomass burning

- Biomass burning source better correlated ($PM_{2.5}$) across all sites but still a local source – the common denominator is meteorology, with cold calm conditions leading to peak biomass burning mass contributions to ambient APM

$PM_{2.5}$



PM_{10}



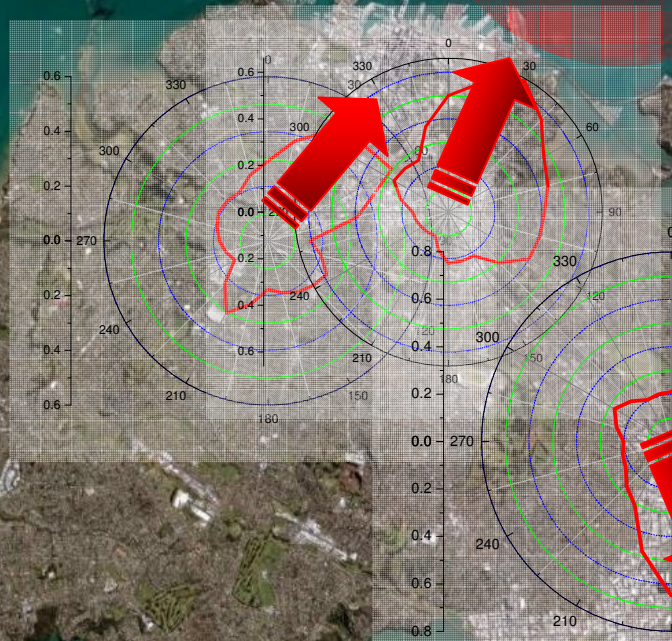
Regional sources – e.g. secondary sulphate

- Secondary sulphate formed by gas-to-particle conversion process
- Precursors can be SO_2 gas or dimethyl sulphides emitted by marine organisms (open ocean)
- Two methods of determining sulphate sources
  - CPF analysis of all samples
  - Back trajectory analysis of regional sulphate event

CPF analysis of sulphate sources

Sulphate source

Hauraki Gulf shipping lanes and port area

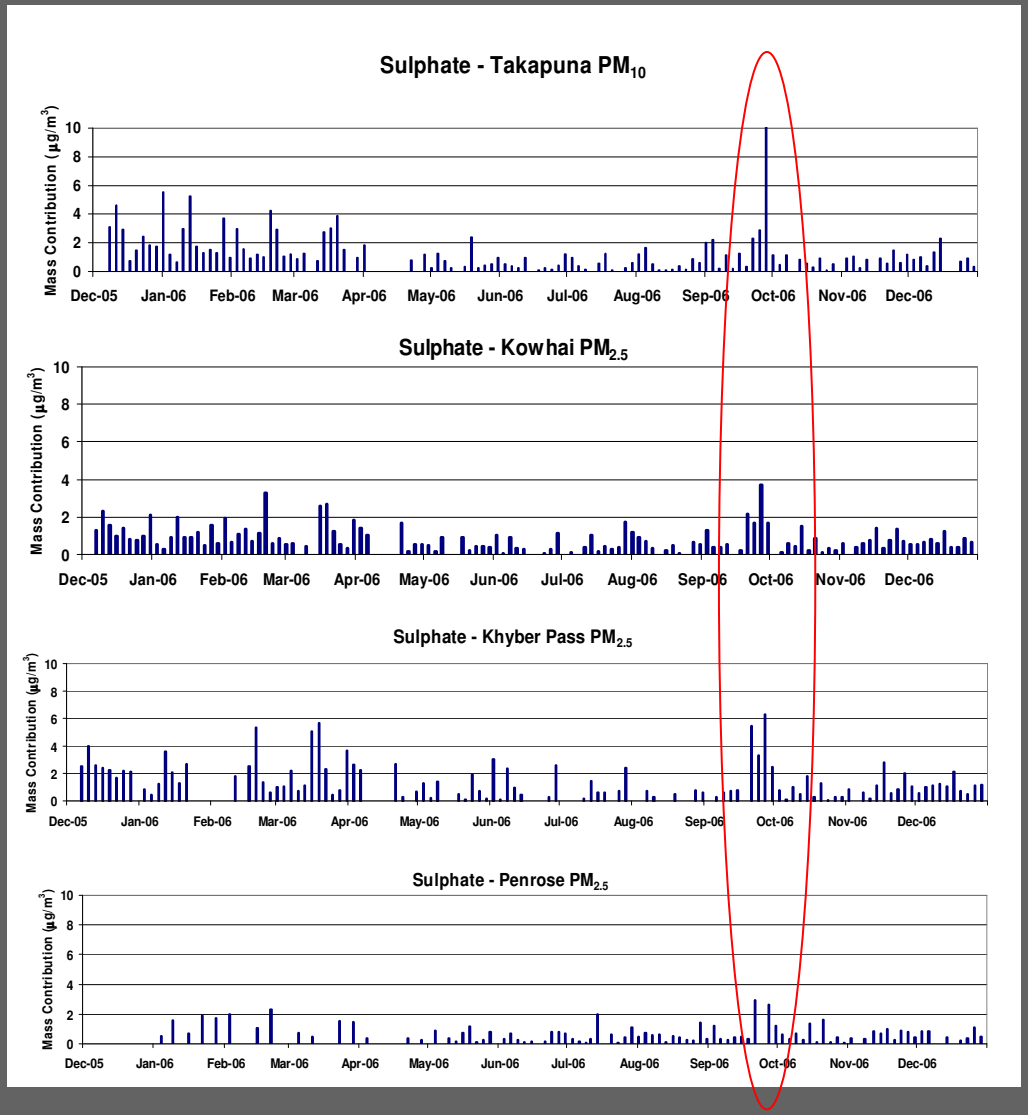


Sulphate source

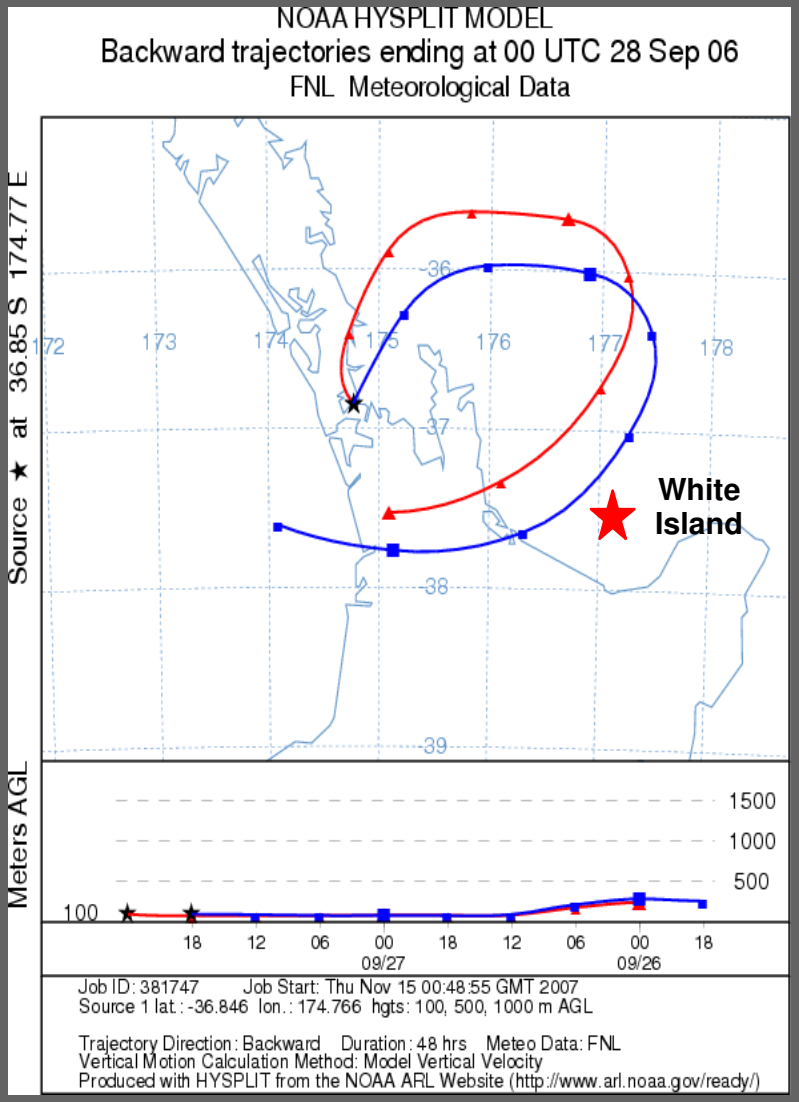
Industry

Regional sulphate 'event' – 28 September 2006

Receptor modelling results for sulphate



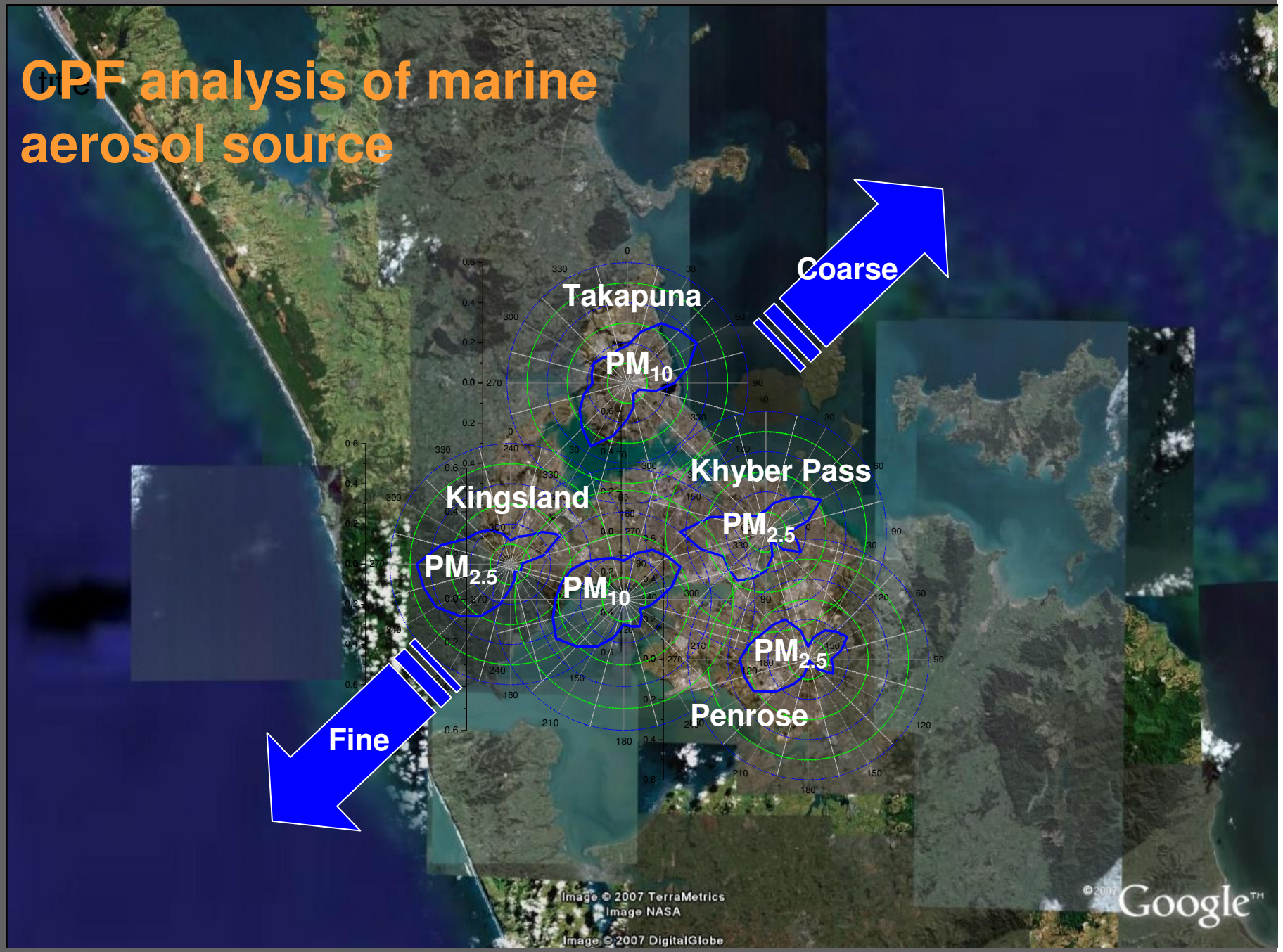
Air mass back-trajectory



And another regional source – marine aerosol

- Marine aerosol is generated by wind and wave action across the oceans
- The finer fraction of marine aerosol ($PM_{2.5}$) can travel long distances
- CPF analysis of marine aerosol source suggests that $PM_{2.5}$ fraction is largely generated in the Tasman and Southern Ocean
- CPF for PM_{10} suggests that coarse marine aerosol particles are generated more locally (Waitemata Harbour, Hauraki Gulf, Manukau Harbour and west coast surf)

CPF analysis of marine aerosol source

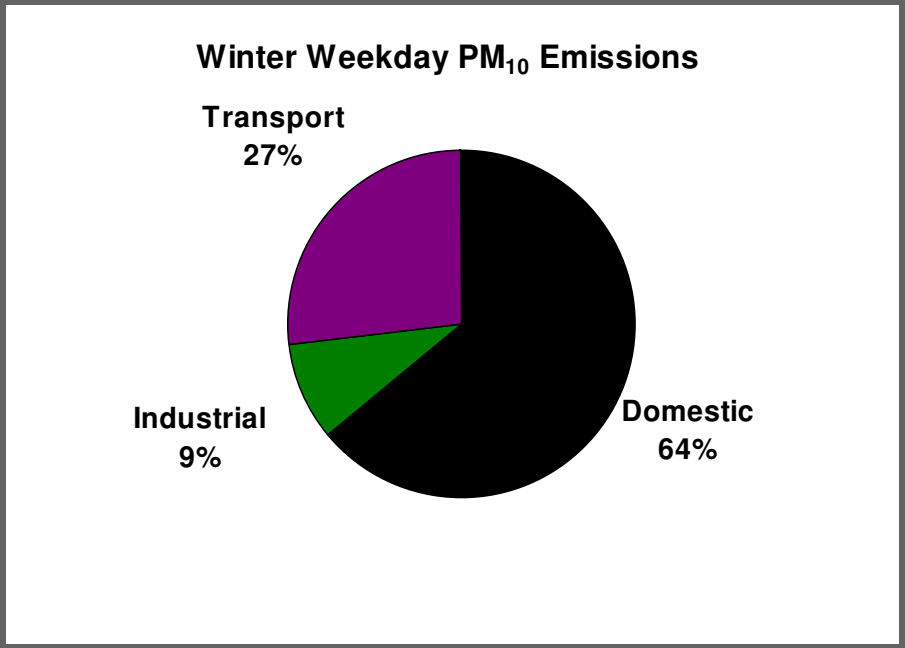


Comparison with emissions inventory

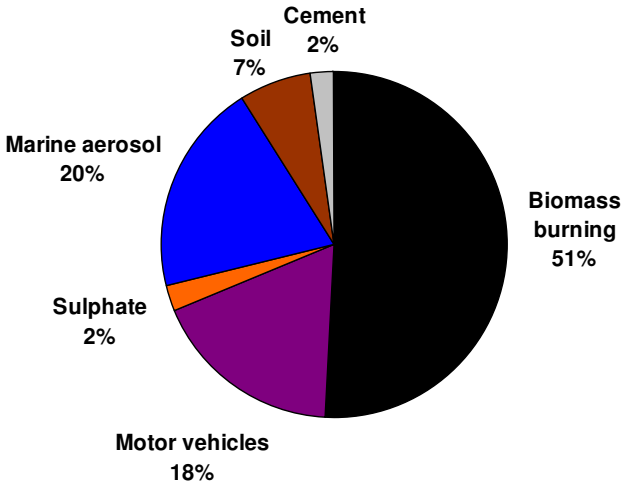
- Receptor models provide an estimate of mass contributions from all sources based on measured concentrations at a particular site
- Emissions inventories provide an estimate of average emissions from specified sources on an annual or daily basis (i.e. average winter day or summer day) based on activity and emissions factors

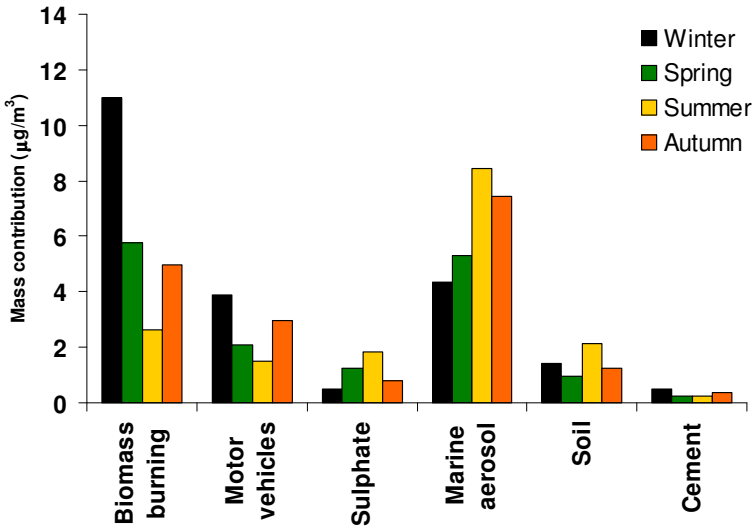
Winter PM_{10}

Emissions Inventory



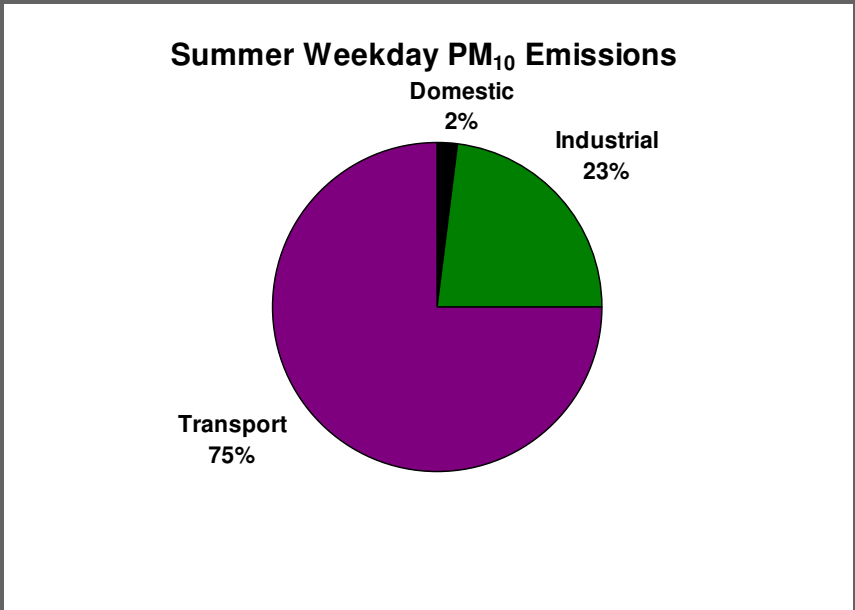
Takapuna



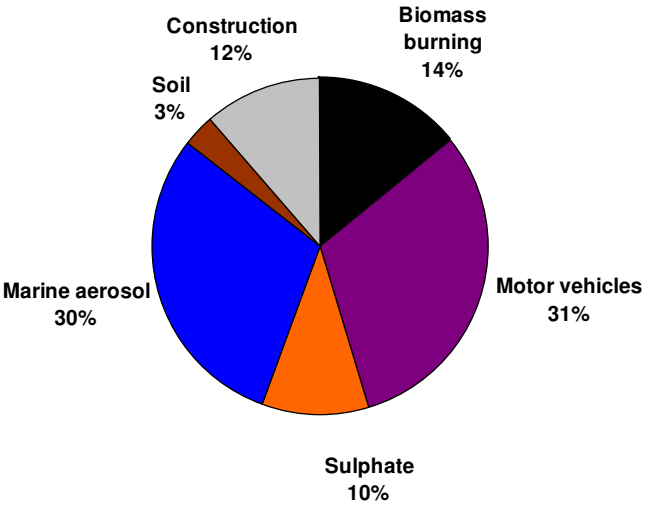


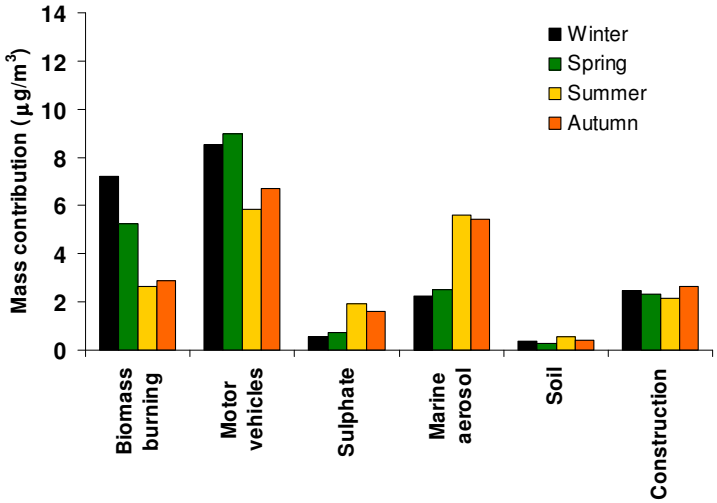
Summer PM_{10}

Emissions Inventory



Queen Street





Summary of Auckland receptor modeling

- IBA provides an effective method of determining elemental concentrations for use in receptor modeling studies
- Receptor modeling has provided a per sample analysis of contributing sources to APM in Auckland allowing the investigation of:
  - Regional, local and one-off sources
  - Daily, seasonal or annual variations
- Marine aerosol is an important contributor to both $PM_{2.5}$ and PM_{10} during summer and PM_{10} all year
- Biomass burning is largely responsible for winter $PM_{2.5}$ and PM_{10} peaks
- Motor vehicle emission sources can also contribute significantly depending on location
- The relative contributions of sources to peak PM events can form the basis of evaluating emissions reduction strategies for locations where National Environmental Standards or Regional Air Quality Targets are exceeded