HazeWatch: A Participatory Sensor System for Monitoring Air Pollution in Sydney

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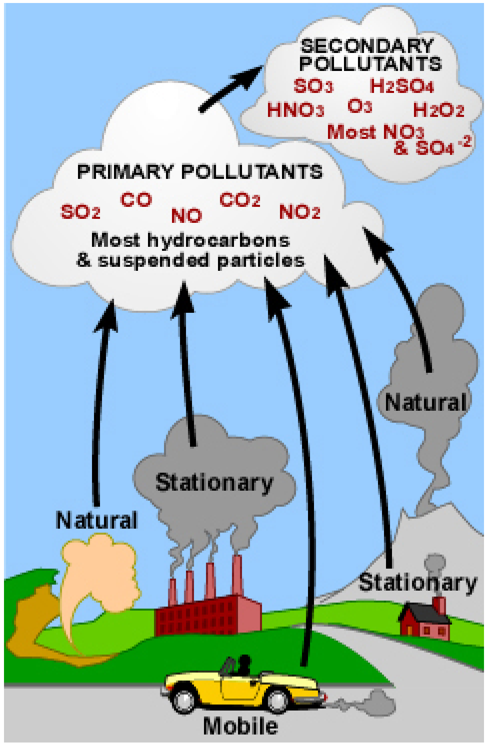
Air Pollution: Effects

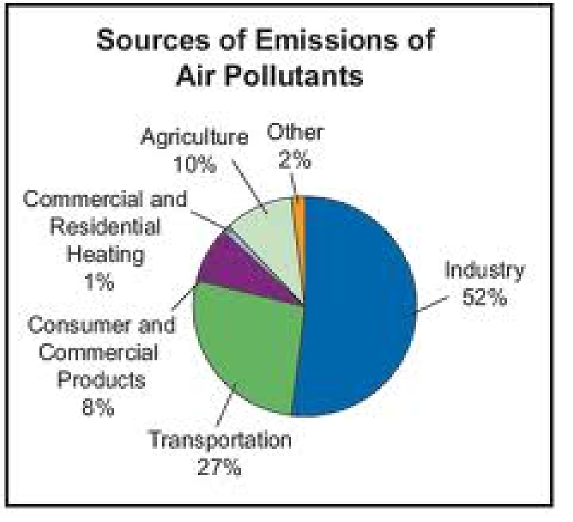
- 1.4 billion urban residents live in areas with air pollution above guidelines [WHO]
  - 2 million deaths worldwide
  - 2.3% of deaths in Australia
  - NSW: $4.7billion in health costs
- Chronic exposure
  - cardiovascular and respiratory mortality and morbidity
- Acute short-term inhalation
  - exacerbates existing conditions asthma, COPD, heart disease

	MAJOR SOURCES	HEALTH EFFECTS	ENVIRONMENTAL EFFECTS
SO_2	Industry	Respiratory and cardiovascular illness	Precursor to acid rain, which damages lakes, rivers, and trees; damage to cultural relics
NO_x	Vehicles; industry	Respiratory and cardiovascular illness	Nitrogen deposition leading to over-fertilization and eutrophication
PM	Vehicles; industry	Particles penetrate deep into lungs and can enter bloodstream	Visibility
CO	Vehicles	Headaches and fatigue, especially in people with weak cardiovascular health	
Lead	Vehicles (burning leaded gasoline)	Accumulates in bloodstream over time; damages nervous system	Fish/animal kills
Ozone	Formed from reaction of NO_x and VOCs	Respiratory illness	Reduced crop production and forest growth; smog precursor
VOCs	Vehicles; industrial processes	Eye and skin irritation; nausea; headaches; carcinogenic	Smog precursor

Air Pollution: Causes

- Regional Air Quality Index (RAQI) system recommends monitoring 5 main air pollutants:
  - Ozone O_3
  - Carbon monoxide CO
  - Sulfur Dioxide SO_2
  - Nitrogen Dioxide NO_2
  - Particulate Matter PM
- Major sources of air pollution:
  - Industrial processes
  - Motor vehicles: cars, trucks, buses





Air Pollution Monitoring in Sydney

- NSW Office of Environment and Heritage runs 15 stations across greater Sydney
- Data published and updated on hourly basis
- AQI reported; Health warnings posted

Pollutants		Ozone O3	Ozone O3	Nitrogen dioxide NO2	Visibility NEPH	Carbon monoxide CO	Sulfur dioxide SO2	Particles PM10
Averaging Periods		1-hour average	rolling 4-hour average	1-hour average	1-hour average	rolling 8-hour average	1-hour average	rolling 24-hour average
Sydney east	RANDWICK	2.6	2.5	0.9	0.09		0.2	9.7
	ROZELLE	2.8	2.6	0.9	0.06	0.3		11.1
	LINDFIELD	2.6	2.3	0.7	0.06		0.2	9.9
	CHULLORA	2.0	2.3	1.5	0.10	0.3	0.2	12.9
	EARLWOOD	1.9	2.1	1.5	0.07			11.2
Sydney north-west	RICHMOND	3.2	2.7	0.3	0.05		0.1	9.6
	ST MARYS	2.4	2.4	0.6	0.08			9.2
	VINEYARD	2.9	2.4	0.2	0.02		0.1	11.2
	PROSPECT	2.2	2.2	0.8	0.07	0.2	0.3	12.6
Sydney south-west	BARGO	2.4	2.4	0.1	0.04		0.0	6.2
	BRINGELLY	2.3	2.4	0.1	0.03		0.0	8.0
	LIVERPOOL							
	MACARTHUR	2.4	2.6	0.3	0.03	0.2	0.0	10.1
	OAKDALE	2.5	2.5	0.1	0.03			5.8
Illawarra	WOLLONGONG	2.6	2.8	0.7	0.06	0.3	0.0	9.5
	KEMBLA GRANGE	2.4	2.5	0.5	0.17			25.4
	ALBION PARK STH							
Lower Hunter	WALLSEND	1.5	2.2	1.8	0.08		0.7	14.9
	BERESFIELD	2.8	2.6	-0.1	0.08		0.1	28.8
	NEWCASTLE	1.5	1.9	1.6	0.03	0.1	1.2	21.6
Central tablelands	BATHURST							
North-west slopes	TAMWORTH							16.4
South-west slopes	ALBURY							11.1
	WAGGA WAGGA							16.4

VERY GOOD	GOOD	FAIR	POOR	VERY POOR	HAZARDOUS

Images From: www.health.nsw.gov.au

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Limitations of Current System

- Poor spatial resolution
  - Sites separated by tens of kilometers
  - Need interpolation models:
    - Complex: land topography, chemical compositions
    - Inaccurate: meteorological conditions
- Do not reflect actual exposures of individuals
  - Spatial heterogeneity
    - Concentrations can change over short distances
  - Mobility patterns of users
    - Time spent and activity level at home, work, travel

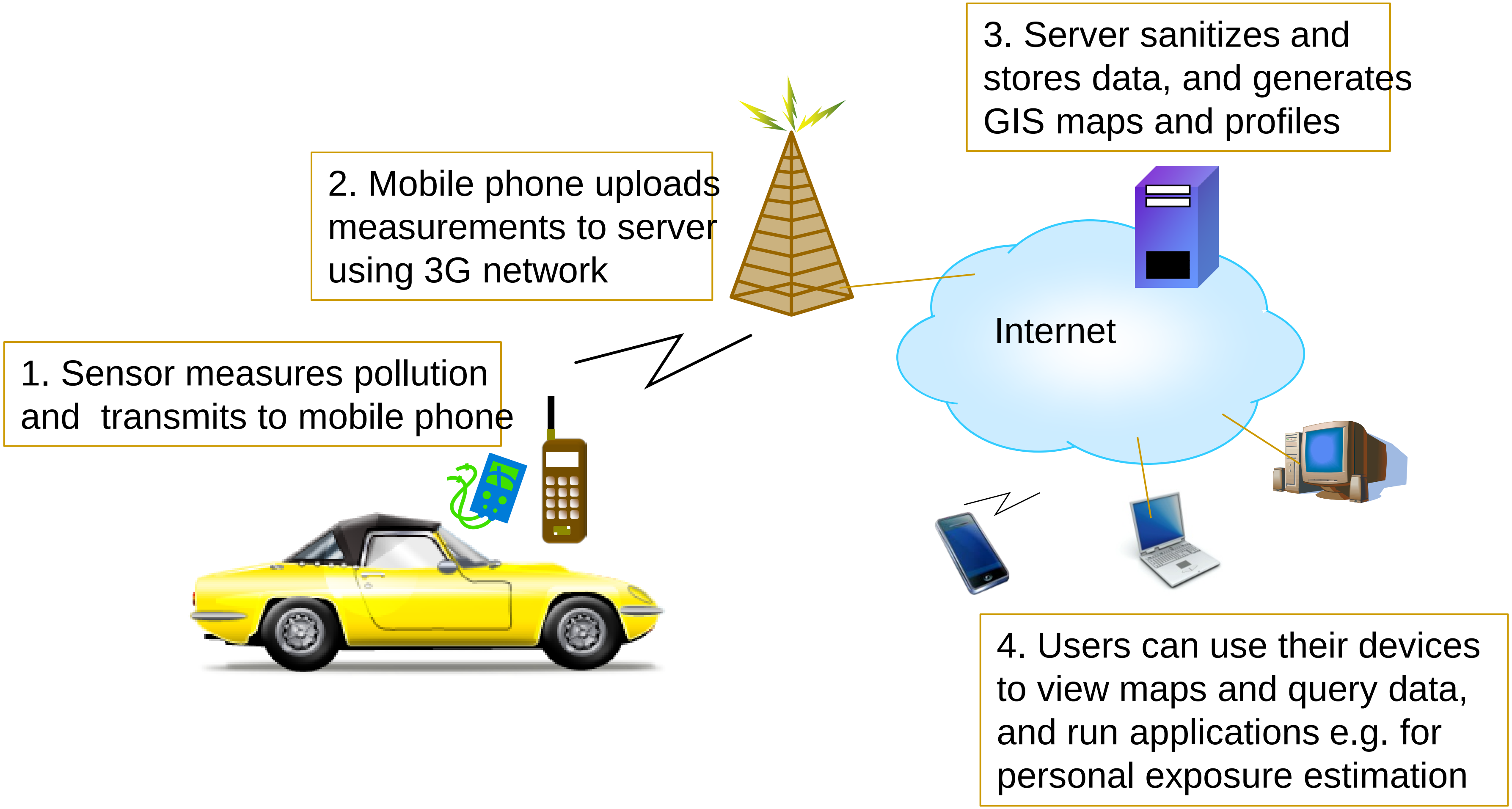
Idea Behind "HazeWatch" System

- "Crowd source" data from users (drivers)
  - Users upload pollution measurement as they drive
  - Measurements stored in "cloud"
  - Displayed as pollution map in real-time
  - Can build cloud-based tools and services around it
- Advantages:
  - Cost-effective: mobile sensors cover more ground
    - E.g. sensor on one bus can cover tens of kilometers
  - Better spatial resolution for same sensors
    - 30-50 mobile sensors can cover a city well?
  - Personalized tools
    - Personal exposure meter, route-planning, …

Existing Designs

- Commercial pollution monitors:
  - Gases: Honeywell GasAlertmicro5
  - Particulate Matter: Met One Aerocet 531
- Research prototypes:
  - MESSAGE project (UK)
  - iSniff (Columbia Uni)
  - MAQUMON (Vanderbilt Uni)
  - City Senspod (Sensaris)
  - Common sense (UC Berkeley)
  - OpenSense (Switzerland)

System Architecture



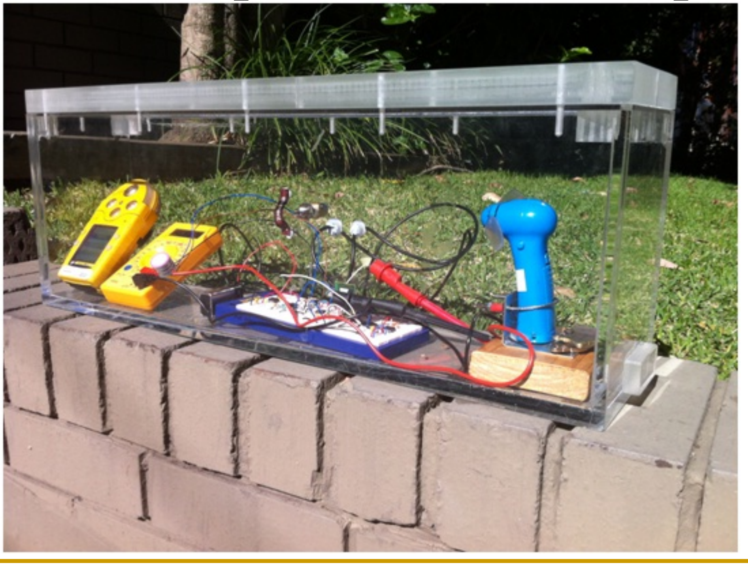
Pollution Measuring Hardware

- Portability: fixed vs personal vs vehicle
- Complexity: on-board GPS, 3G?
  - Sensors, micro, bluetooth, battery
- Gas sensors: CO, NO_2, O_3
  - Metal oxide vs electrochemical

Calibration and Mounting

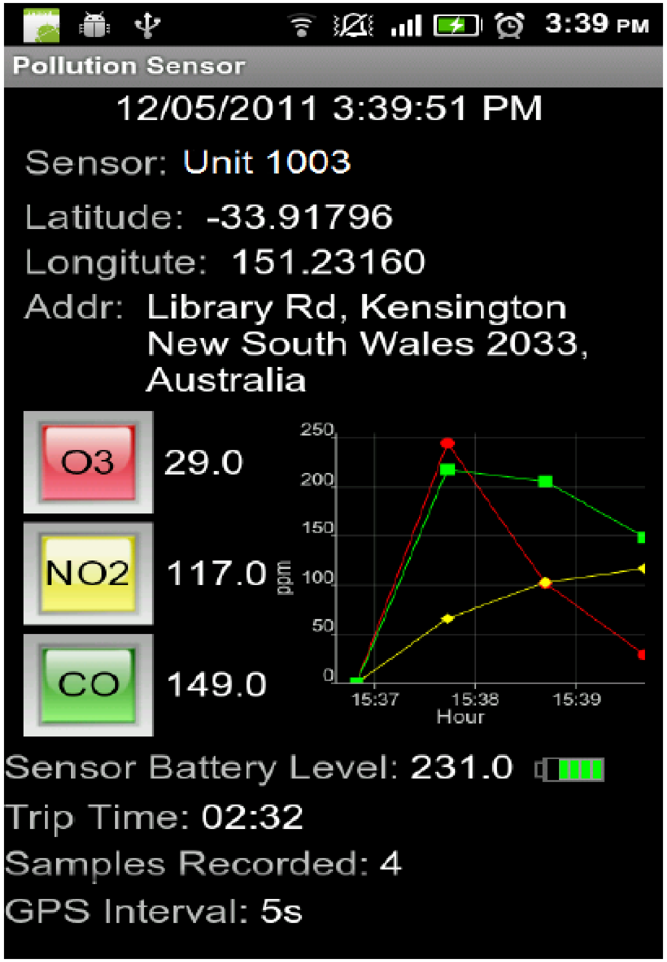
- Calibration: challenging!
  - Custom-built air-tight container
  - CO from car exhaust, NO_2 from nitric acid + Copper
  - Comparison to commercial monitor

- Casing and mounting:
  - Custom casing vs off-the-shelf
  - Mounting: front/rear, low/high, into/across wind, …

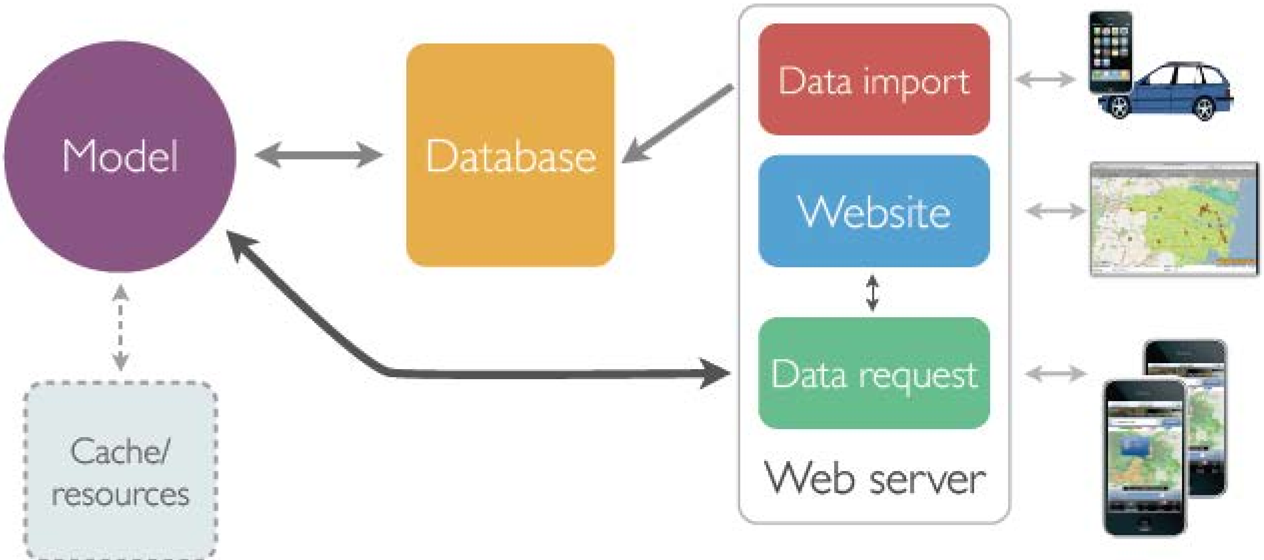


Data Upload

- No GPS/3G in device
- Bluetooth to mobile phone
- Platform: Android
- User visualization:
  - Unit id, location/address
  - Pollution readings
  - Battery level
- 3G upload to server:
  - Time and location stamped
  - Update intervals configurable



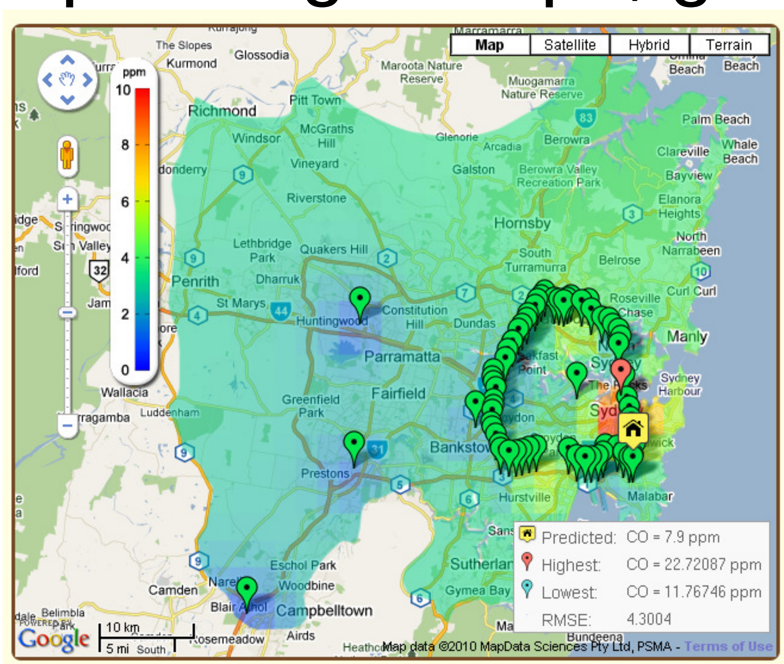
"Cloud" Server Software

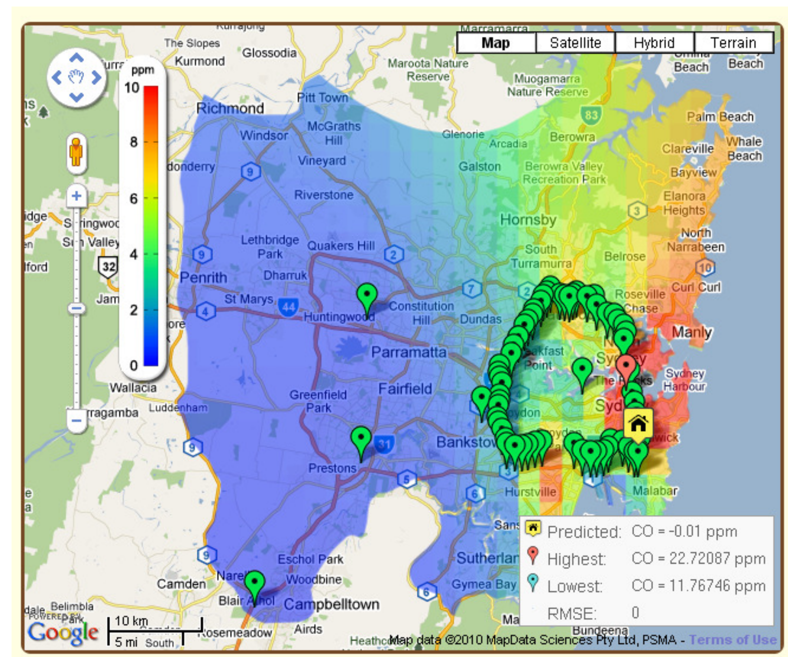


- Located in UNSW data center
  - Database: MySQL
    - User contributed data and dept. environment data
  - Model: interpolation methods
  - Web-server: XML based import and export

Modelling and Mapping

- Choices: interpolation, regression, dispersion
- Two interpolation models implemented:
  - Inverse distance weighting vs ordinary kriging
- Map: Google maps, gridded colour contour

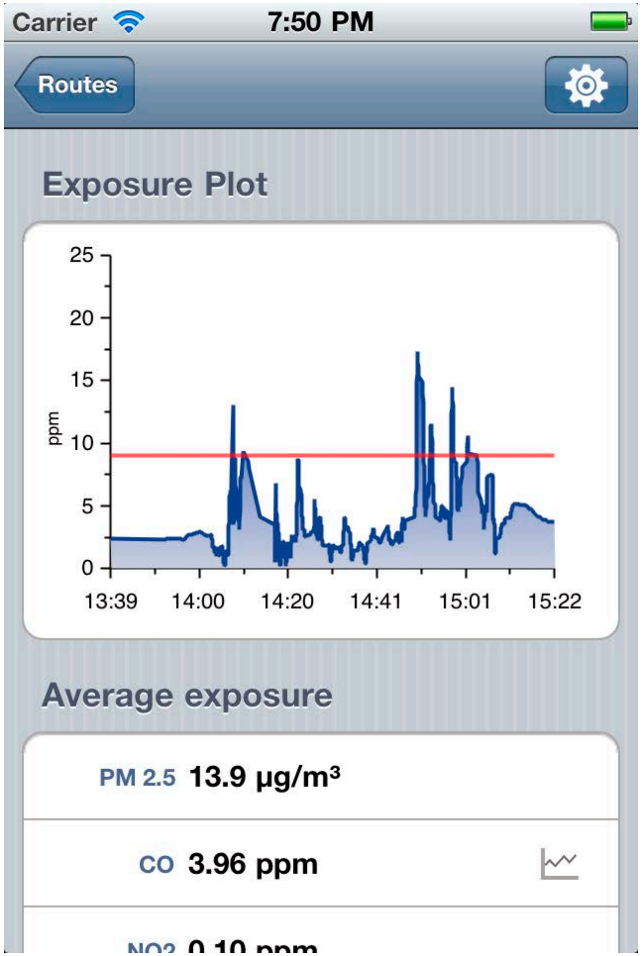




Live at: http://www.pollution.ee.unsw.edu.au

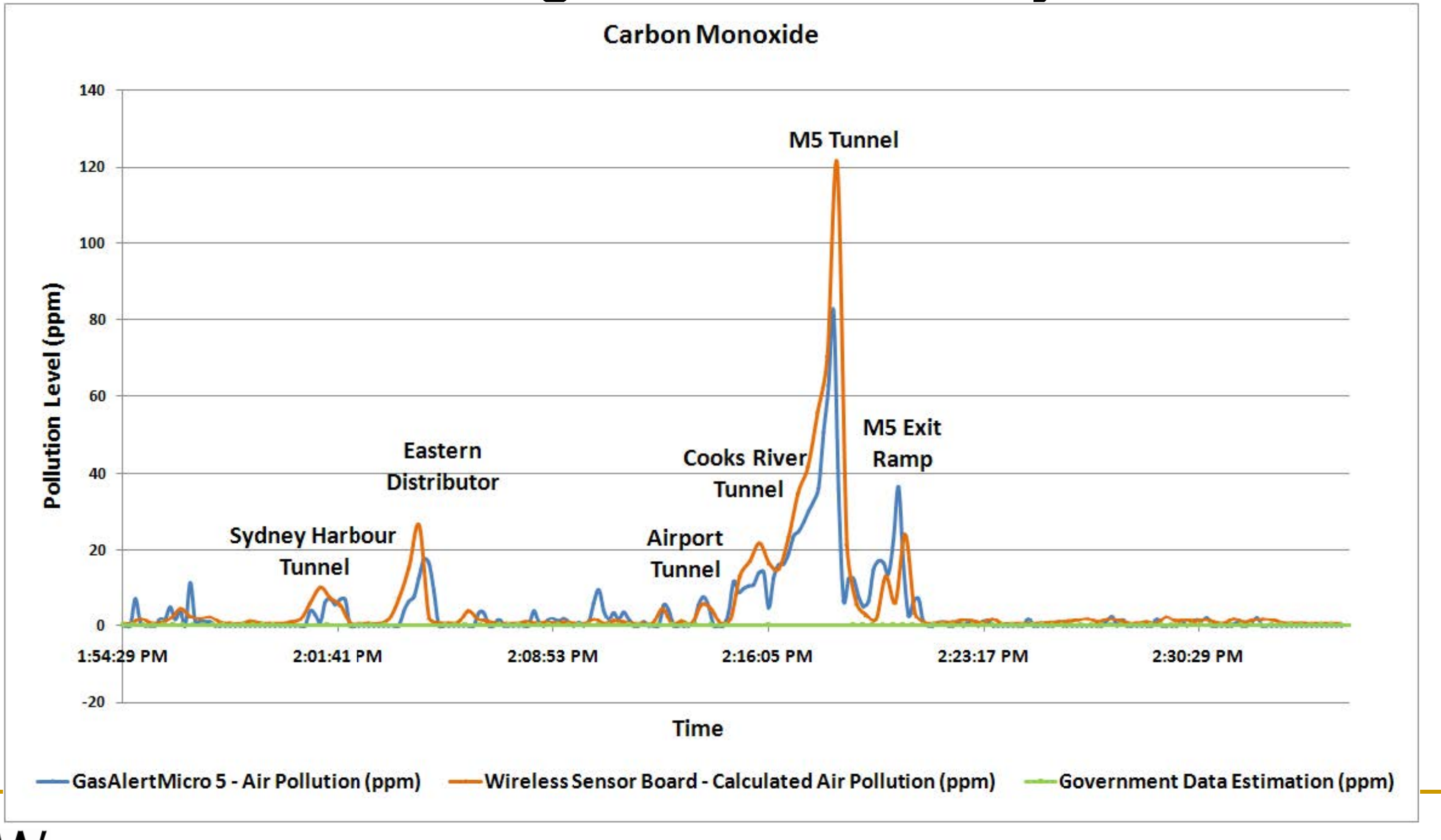
Personal Exposure App

- Records location periodically
- Fetches pollution estimate from model on server
  - User need not carry hardware
- Displays:
  - Route
  - Plot of concentration
  - Mean exposure
- Can aid medical studies correlating exposure to health outcomes



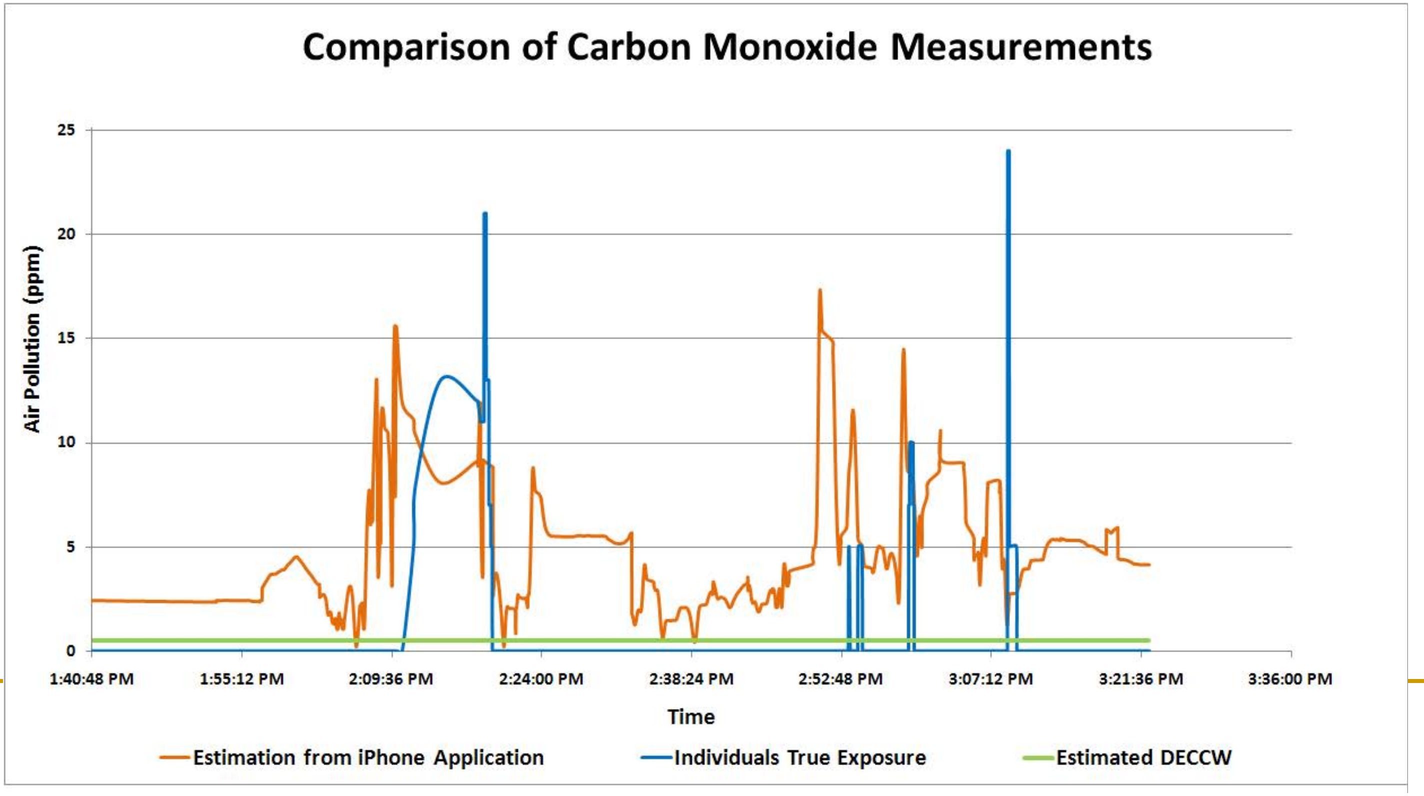
Field Trial 1: Single Driver

- High spatial variation: tunnels and intersections
- Our unit corroborates well with commercial unit
- Data from nearest govt. site is very low



Field Trial 2: Multiple Drivers

- Subject has no hardware, uses estimation app
- Estimate reasonable but not great:
  - Still better than govt. estimate
  - Need higher deployment density



Challenges

- Highly inter-disciplinary, need expertise in:
  - Sensors, calibration (Chemistry)
  - Circuits, comms (Electrical Eng.)
  - Packaging, mounting (???)
  - Cloud software & db, mobile apps (Computer Sc.)
  - Pollution modeling (Atmospheric Sc.)
  - Health outcomes (Medical)
- Mass production and deployment strategy ?
- How to ensure data is of good quality ?
- Uptake of personal tools ?
- Validity for clinical studies ?

Conclusions

- Current systems for air pollution monitoring
  - Are spatially coarse
  - Do not provide personalized services
- Participatory sensing (cheap hardware + mobile apps) can:
  - Yield fine-grained spatial measurements e.g. within tunnels
  - Enable personalized tools for reactive exposure estimation and proactive route mapping
  - Inform clinical studies of impact of air pollution on health
  - Offer viable alternative to waiting for govt. action
- Future work:
  - Emerging off-the-shelf pollution measuring hardware (e.g. NODE)
  - Combine pollution exposure with human activity levels (e.g. Fitbit)
- Project web-page: http://www.pollution.ee.unsw.edu.au