The mortality effect of ship related PM2.5 in Sydney

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SCHOOL OF PUBLIC HEALTH

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Overview

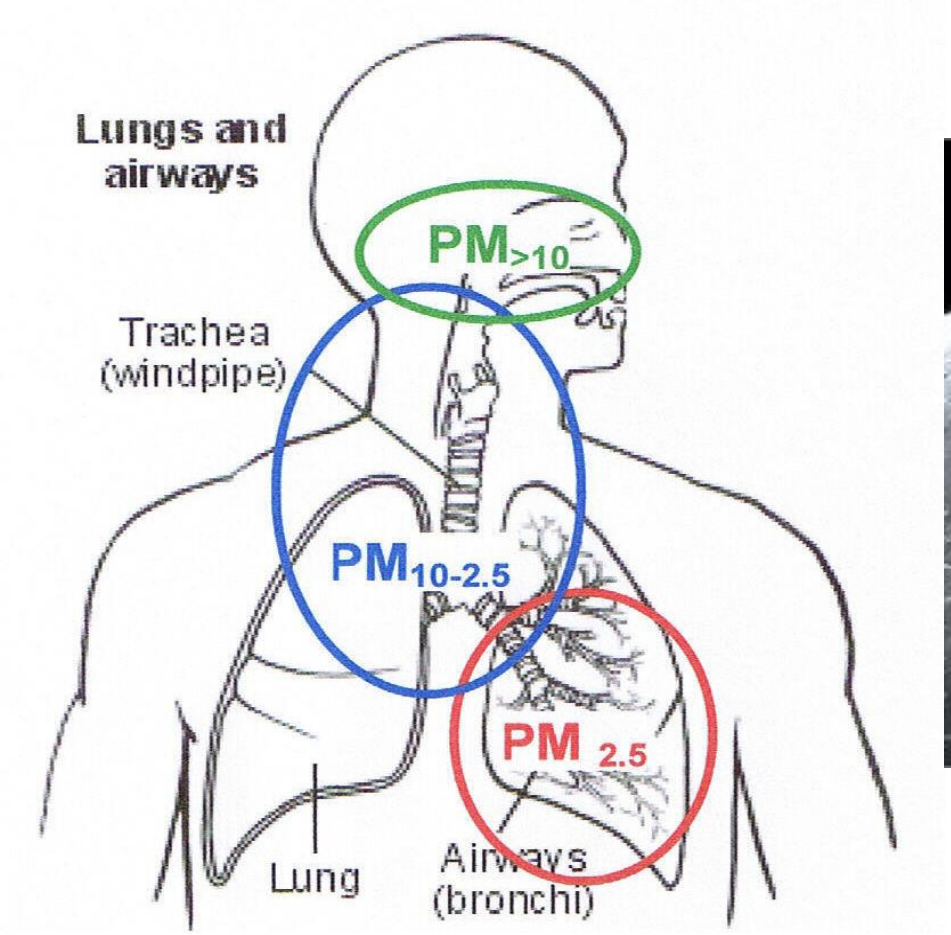
- Background on air pollution and health
- Methods for assessing health burden of air pollution in Sydney
- **Health burden** of **past ship exhaust emissions** in Sydney GMR
- **Health benefits** of policy options to **reduce future ship exhaust emissions** in Sydney GMR
- Results - based on journal paper currently under review

Background

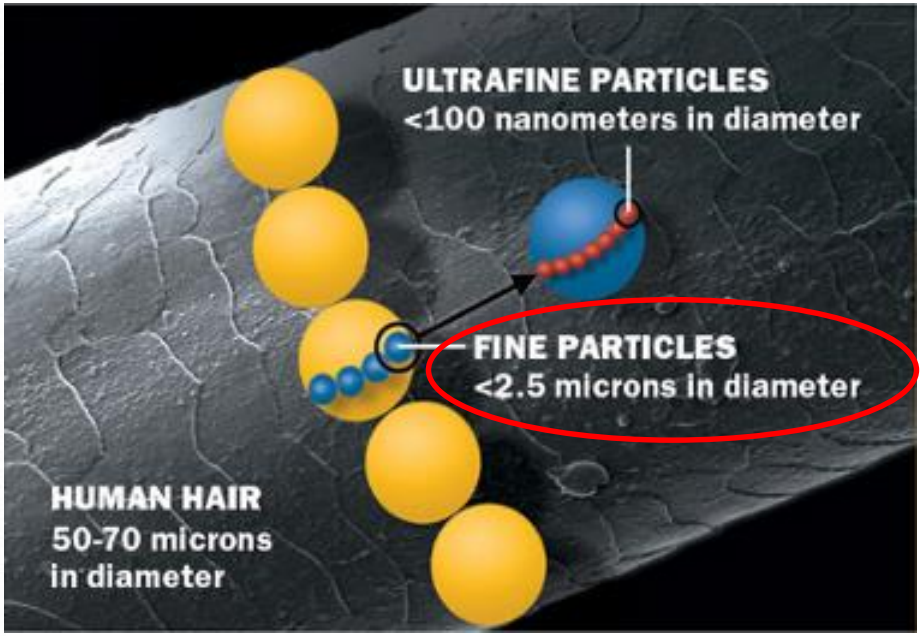
- Sydney generally has good air quality by international comparisons
- Annual average PM2.5 generally < 8 µg/m3
- One hour ozone standard (0.10 ppm) exceeded on average 8 times/year
- National particle standards currently under review – proposal for PM standard based on continual reduction in PM over time
- State government considering policy options to reduce air pollution.

Why is Particle Size Important?

Particle size influences how deeply the penetrate lungs and airways



Source: http://en.wikipedia.org/wiki/Respiratory_system



Source: http://now.tufts.edu/articles/big-road-blues-pollution-highways

Particulates and Health - Weight of Evidence

Long term $PM_{2.5}$ exposures – years / decades

Reproductive / developmental

Respiratory Morbidity

Mortality (reduced life expectancy)
Cardiovascular Morbidity

Not likely | Inadequate | Suggestive | Likely | Causal

Central Nervous System

Respiratory Morbidity

Cardiovascular Morbidity

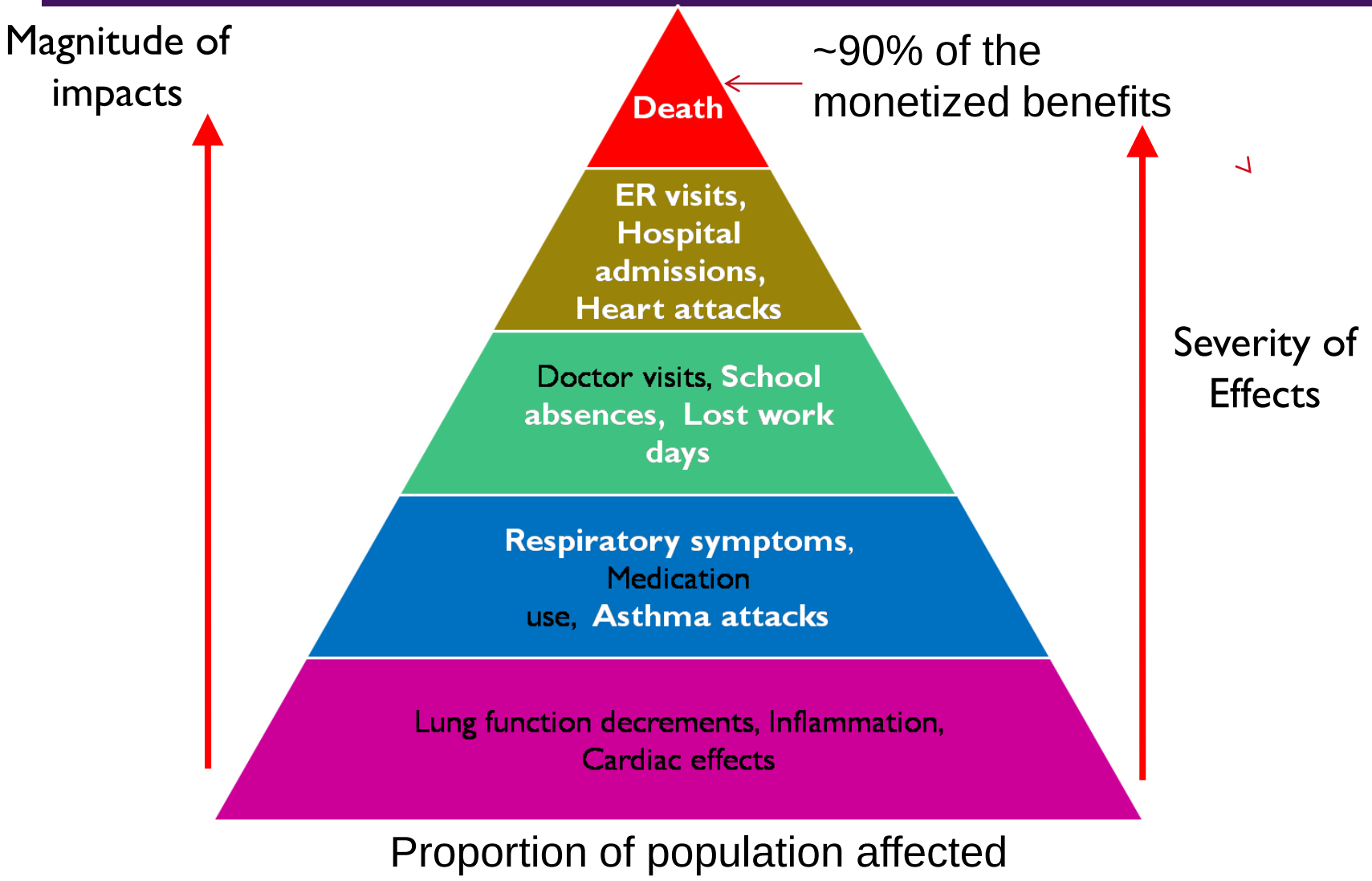
Mortality

Short term $PM_{2.5}$ exposures - days

IARC 2013 classification of **air pollution and particulates** as a carcinogen (Loomis, D, The carcinogenicity of outdoor air pollution, The Lancet Oncology, 2013;14(13):1262–1263)

Source: US EPA 2009. Integrated science assessment for particulate matter

"Pyramid of Effects" from Air Pollution



Mortality Effect of PM2.5

Burden Calculation: Past Exposure

$$\Delta Y = Yo\ (1\text{-}e^{-\beta \Delta PM}) * Pop$$

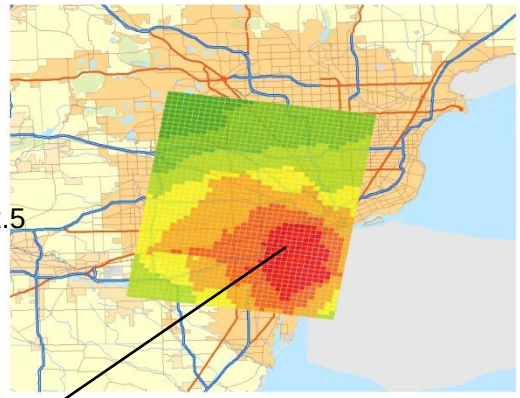
ΔY – Mortality Change

Yo – Baseline Mortality Rate

ß – Mortality Effect Estimate (epi study)

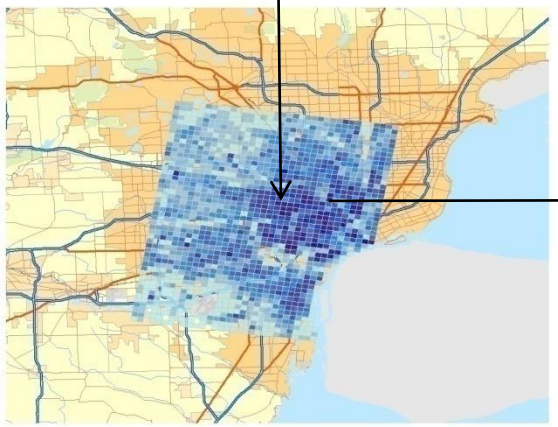
Pop – Exposed population

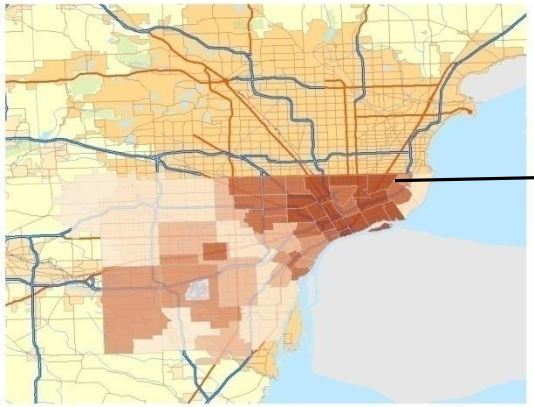
Air Quality Change - $\Delta PM_{2.5}$



Population By Age

Baseline Mortality Incidence





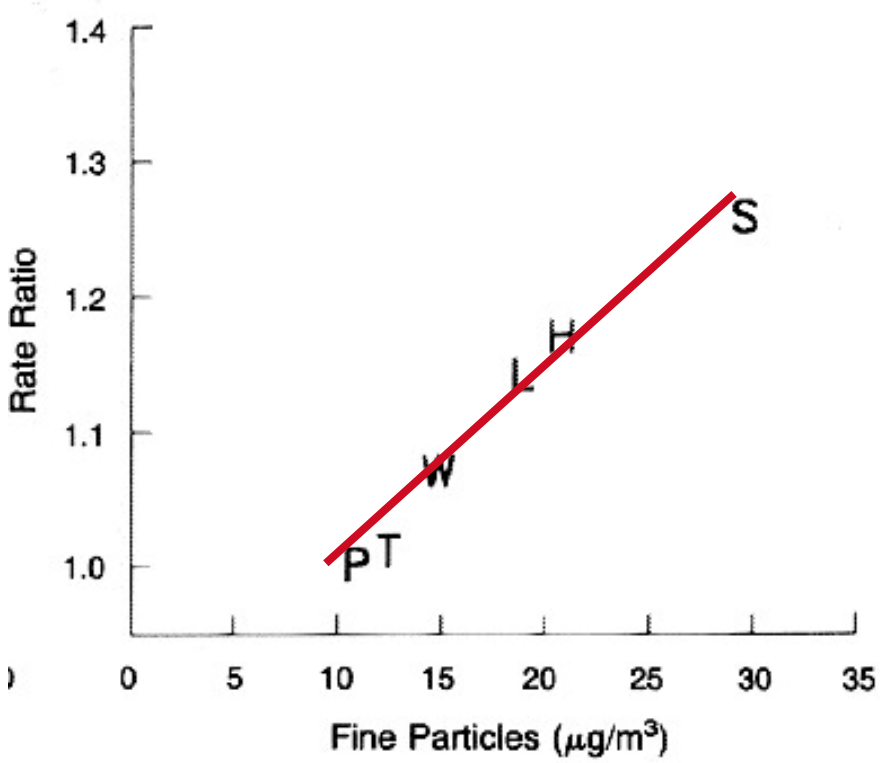
Effect Estimate

Attributable Premature Mortality Increase/ Decrease due to "Scenario"

Source: http://www2.epa.gov/benmap

Mortality Effect Estimate Used in This Study

Mortality and PM2.5: Harvard Six Cities Study



ß – Mortality Effect Estimate used in this Study

- **Risk of premature mortality due to PM2.5 increases by 6.2% per 10 µg/m3 increase in PM2.5**
- **Ref: Hoek et al 2013 – summary estimate from 13 European and North American studies**
- **Recommended by WHO 2013 – HRAPIE Report**

Annual Mean air pollution: P Portage, Wisconsin; T Topeka, Kansas; W Watertown, Massachusetts; L St. Louis; H Harriman, Tennessee; and S Steubenville, Ohio.

Ref: Dockery et al.N Engl J Med 1993; 329:1753-1759

Burden Calculation – Past Exposure

$$\Delta y = (1-e^{\beta \cdot \Delta x}) \cdot y_o \cdot Pop$$

Where: Δy: change in number of deaths, ie: attributable premature mortality
Δx: change in air pollution exposure
β: risk coefficient from epidemiological study
y_o: baseline mortality incidence
Pop: exposed population

Estimate

- attributable premature mortality
- reduced survival time - Years of Life Lost (YLL)
- based on exposure change for population (not individuals)

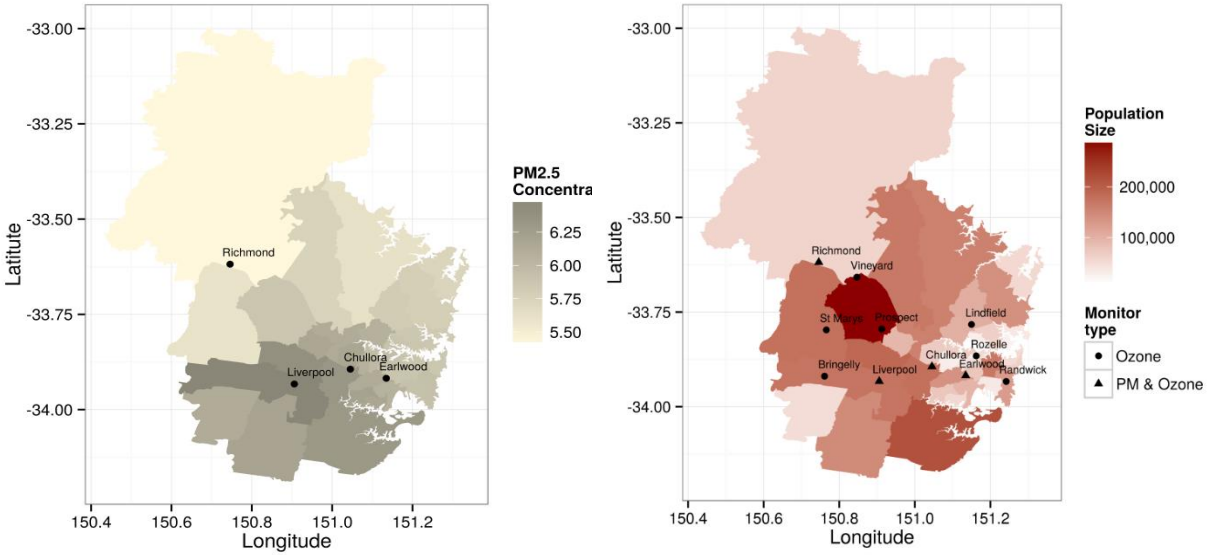
Health Burden of PM2.5 Exposure in Sydney

Broome R, Fann N, Fulcher C, Duc H, Morgan G. The health benefits of reducing air pollution in Sydney, Australia. Environmental Research 2015;143:19-25

What is the annual burden of mortality and hospitalization associated with exposure to anthropogenic PM2.5

- 430 premature deaths annually at typical ages (2.1% of all mortality)
- 5800 YLL annually

$PM_{2.5}$ Population



Sydney Shipping Study – Study Questions

- **Annual burden** of mortality attributable to **past and current exposure** to **all ship-related PM2.5 ?**
- **Potential mortality benefi**t of two **interventions to reduce ship exhaust emission** of **PM2.5** ?

Ship exhaust emissions scenarios: **Sydney GMR**, **July 2010 to June 2011**

Baseline (Ships use fuel with a sulfur content of 2.7%) compared to:

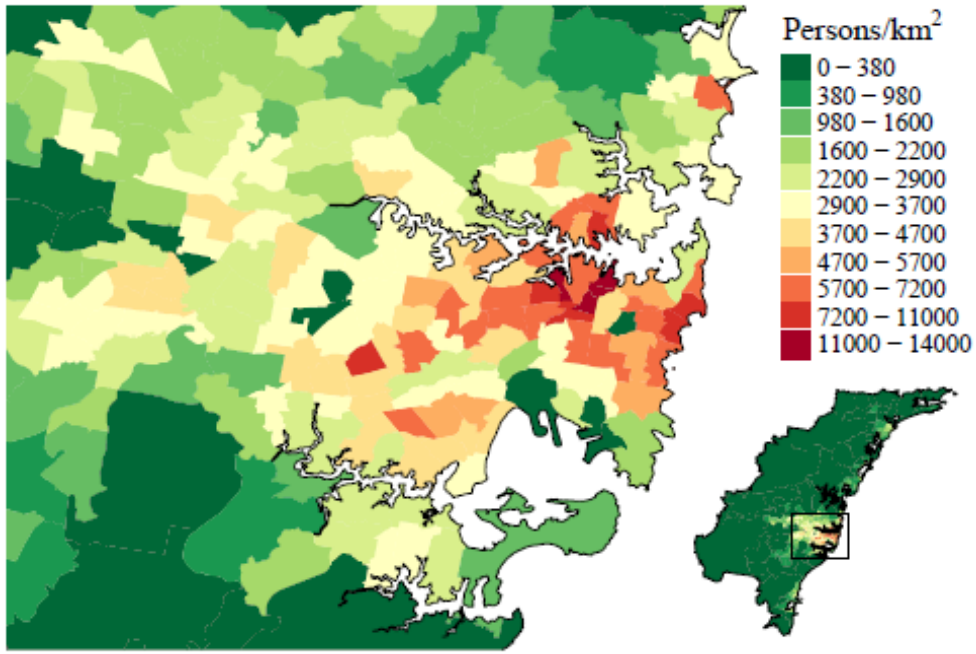
1 **No ships**

2 **Ships at berth** within the GMR use **fuel with a sulfur content of 0.1%**

3 **Ships within 300km** of Sydney use **fuel with a sulfur content of 0.1%**

Population exposed

- Population density: Sydney Harbour and Port Botany by SA2, 2010/11
- Sydney GMR population 10/11:
  - 5.4 million,
  - majority in the urban centres of Sydney, Newcastle and Wollongong.
- Population weighted change in exposure for each SA2

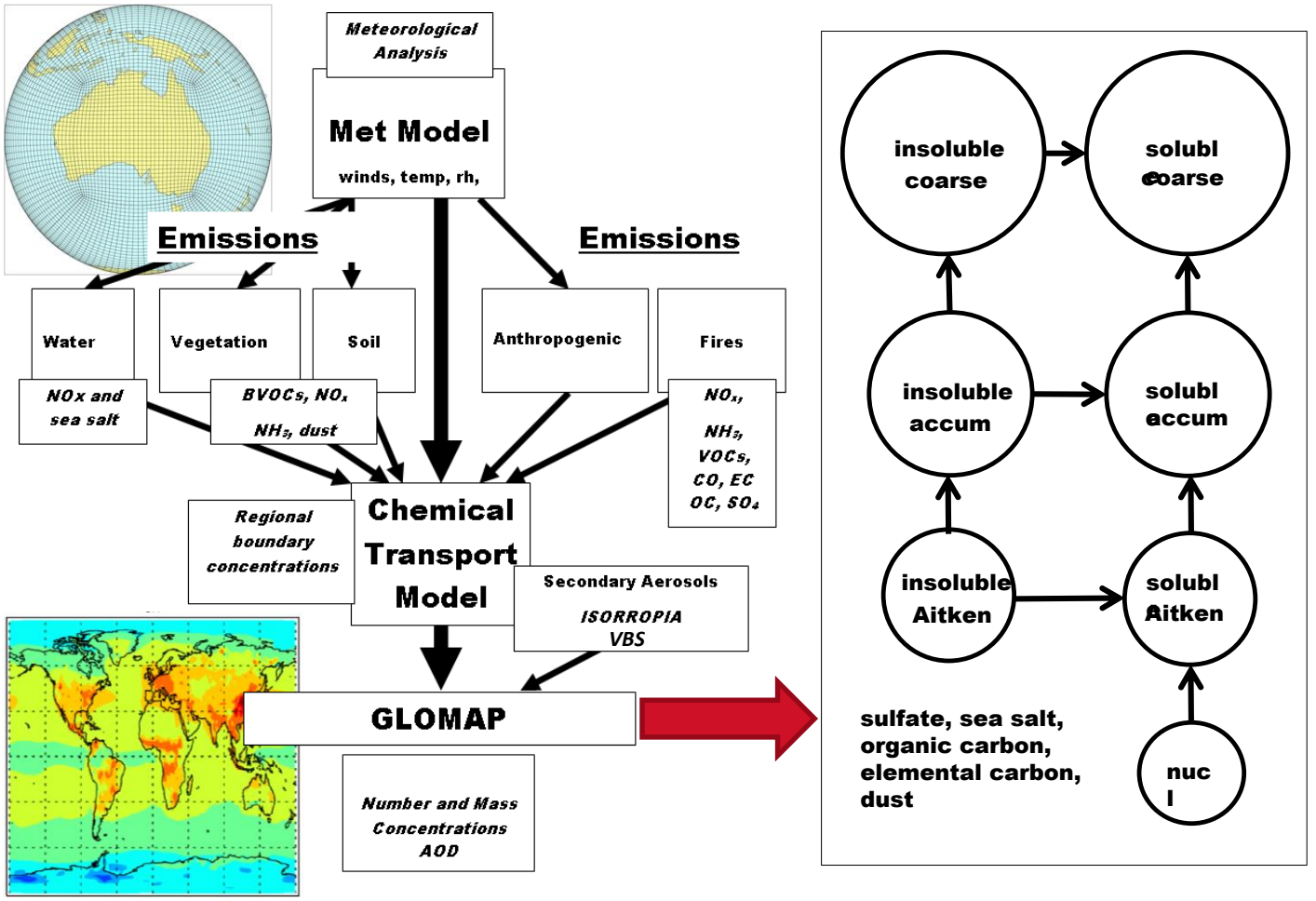


- Aggregated SA2s to Sydney GMR age specific PM2.5 exposure change.
- Estimate mortality burden/ benefit based on Sydney GMR exposure change for Sydney GMR population

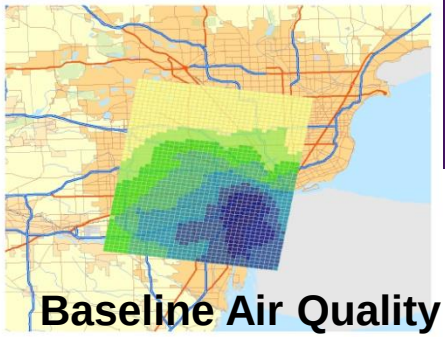
Ship exhaust related exposures

- Comprehensive ship engine exhaust emissions inventory (Goldsworthy 2015)
  - detailed ship movement data, emissions resolved hourly 1km grid
  - ship emissions while in-port, while transiting between ports and while at anchorage outside ports.
- Chemical Transport Modelling system (Martin Cope CSIRO)
  - Nested modelling domains.
  - Three inner domains: hourly ship emissions data 9km, 3km, 1km grids
  - Emissions based data other than shipping: NSW EPA 2008 emissions inventory
  - PM2.5 exposure due to ship engine exhaust emissions = difference between the scenarios.
  - Blending with monitoring data to generate optimal exposure fields within 1km domain

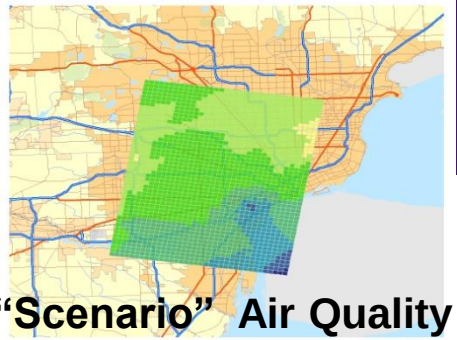
Atmospheric modelling system



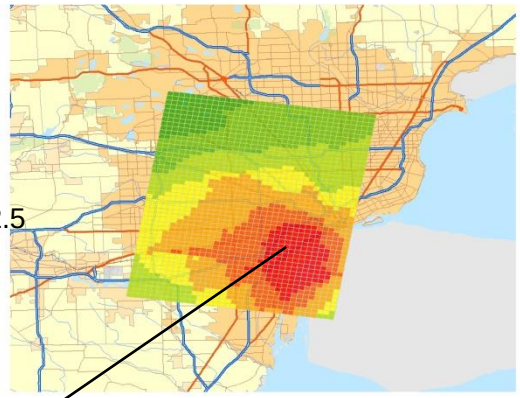
Mortality Effect of PM2.5



Baseline Air Quality



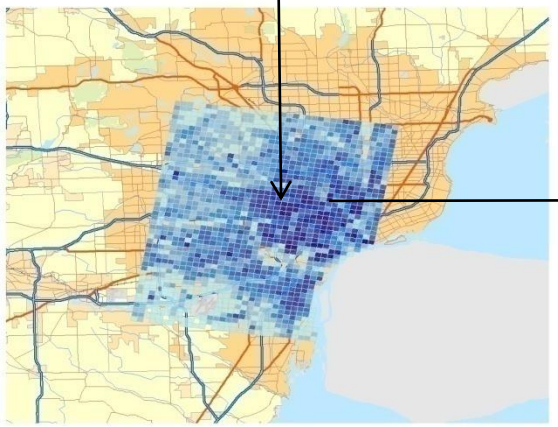
"Scenario" Air Quality

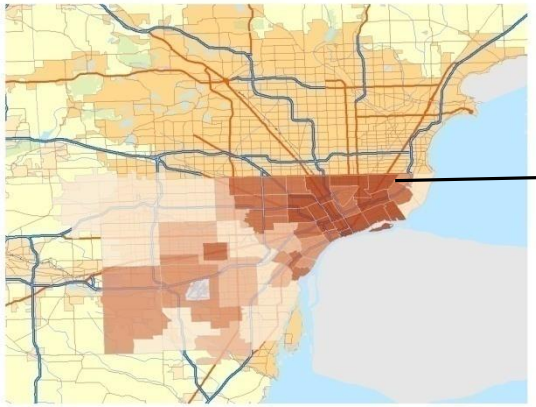


Air Quality Change - $\Delta PM_{2.5}$

Population By Age

Baseline Mortality Incidence





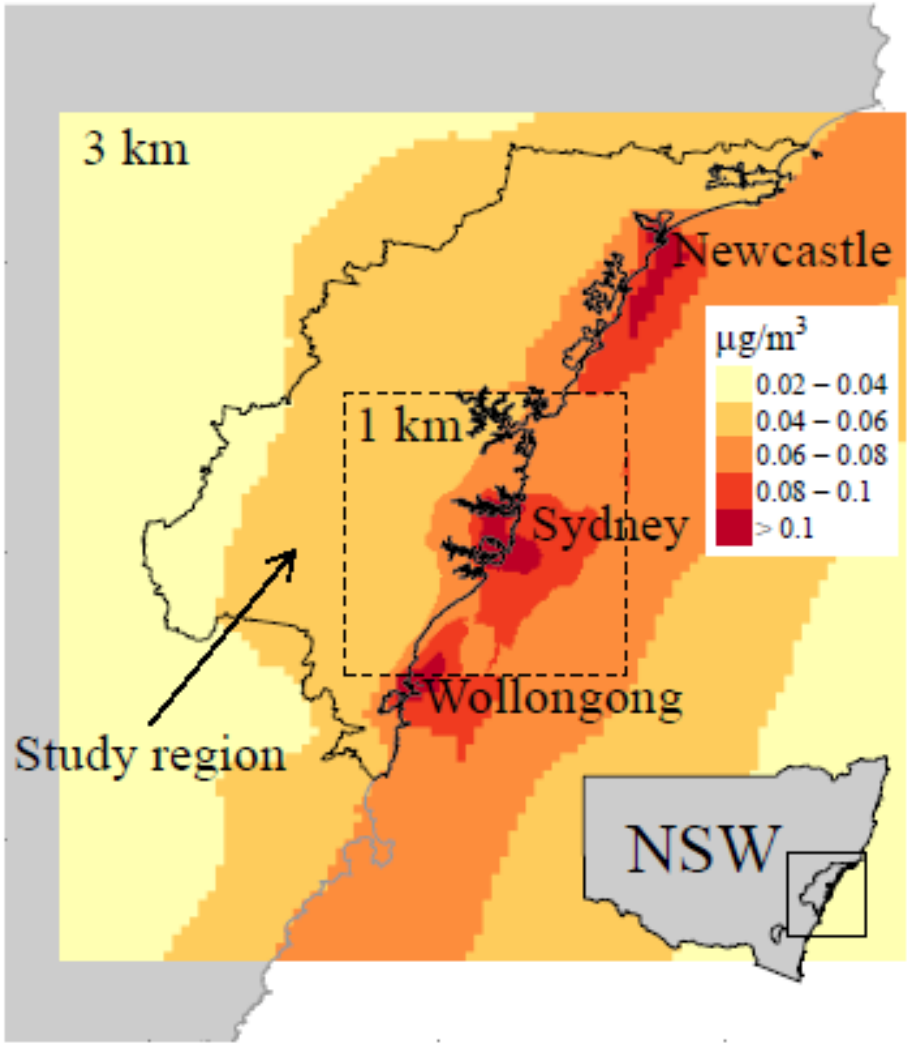
Effect Estimate

Attributable Premature Mortality Increase/ Decrease due to "Scenario"

Source: http://www2.epa.gov/benmap

Ship exhaust related PM2.5 exposure

- Population weighted-mean annual average PM2.5 concentration within the 1km region:
  - 4.6 µg/m3
  - SA2 range: 2.9 µg/m3 to 7.4 µg/m3
- Study region, 3km and 1km grids, 2010/11 annual average ship-related PM2.5 concentration
  - 1.9% of total population weighted-mean PM2.5 concentration
  - SA2 max = 9.4%.



GMR population exposure distribution PM2.5 – all ships (based on 2010/2011)

- Annual average **ship-related PM2.5**
  - Sydney GMR = 0.085 µg/m3.
  - 1.9% of all Sydney GMR PM2.5
  - Up to 9.4% of SA2 (suburb) PM2.5
  - Port Botany SA2 highest: 0.62 µg/m3 (no permanent residents)
  - 1.1 million (20% of population) in SA2s with > 0.1 µg/m3

GMR population exposure distribution PM2.5 – low sulfur scenarios (base on 2010/2011)

- Annual average **low-sulfur fuel at berth ship-related PM2.5**:
  - maximum reduction SA2: 0.41 µg/m3 (75%).
  - 130 000 (2.4% of the GMR population) reside in SA2s with ship related PM2.5 > 0.1 µg/m3.
  - GMR average reduction: 0.021 µg/m3 (25%).
- Annual average **low-sulfur fuel within 300 km GMR ship-related PM2.5**
  - Maximum reduction in SA2: 0.47 µg/m3 (86%).
  - no SA2s > 0.1 µg/m3.
  - GMR average reduction: 0.048 µg/m3 (56%).

Mortality Burden Results – Sydney GMR

- **Mortality burden of 2010/11 ship related PM2.5**
  - 220 YLL were lost as a result of exposure to ship-related PM2.5 (95% CI: 140 – 290).
  - The attributable number of deaths in 2010/11 was 17 (95% CI : 11 – 22).
  - The distribution of YLL among all people who died in 2010/11 is unknown
  - Given that PM2.5 plays a role in induction and acceleration of chronic cardiopulmonary disease, it is likely that ship-related PM2.5 had an impact on the timing of death of many more people then the estimated attributable number of deaths in 2010/11, particularly those who died from cardiopulmonary causes.

Mortality Benefits Results – Sydney GMR

- **Mortality benefit of low sulphur fuel interventions to 2020**
  - Low-sulfur fuel at berth would, over twenty years result in:
    - gain of 390 life-years (95% CI: 260 – 520),
  - Low-sulfur fuel within 300 km would, over twenty years, result in:
    - gain of 920 life-years (95% CI 309 : 600 –1200).

Conclusions

- 2010/2011 ship exhaust emissions
  - 1.9% of all Sydney GMR PM2.5 exposure
  - Up to 9.4% of PM2.5 exposure in some suburbs
- Ship use of low-sulphur fuel at berth
  - maximum suburban reduction of ship-related PM2.5 of 75%
  - reduce average ship related PM2.5 by 25%.
- Ship use of low-sulphur fuel within 300 km of Sydney
  - Maximum suburban reduction of ship-related PM2.5 by 86%
  - reduce average ship related PM2.5 by 56%.

Conclusions

- Use of low sulphur fuel within 300km of Sydney GMR provides more than double the mortality benefit compared to only use of low sulphur fuel at berth
- Future ship exhaust emissions in the Sydney GMR expected to increase compared to 2010/2011 levels
- Mortality benefit estimates to 2020 (or 2025) likely underestimates as do not account for increased shipping activity.
- In addition to the mortality benefits assessed in this study, reductions in ship emissions would reduce the incidence of other PM2.5-related health effects and health effects related to exposure to other air pollutants emitted by ships.

Conclusions

- Consistent with similar studies - Confidence intervals reflect uncertainty from epidemiological study mortality risk estimate only
- Numerous other sources of uncertainty in this assessment. Exposure difference approach help minimise these uncertainties.
- Results support control strategies that seek to reduce emissions of air pollution from ships within the NSW GMR and throughout Australia
- Due to linear exposure response relation between health and PM2.5, substantial health benefits would accrue from further reductions in PM2.5 in Sydney GMR, and throughout Australia
- Journal paper:
  - Broome RA, Cope ME, Goldsworthy B, Goldsworthy L, Emmerson K, Jegasothy E, Morgan GG. The mortality effect of ship-related fine particulate matter in the Sydney greater metropolitan region of NSW, Australia“. Environment International, 2016;87:85-93

THANK YOU

On behalf of the study team

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