SPATIAL AND TEMPORAL ALLOCATION OF EMISSIONS FROM WOOD COMBUSTION

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Summary

Results from a domestic survey for the Port Phillip region were analysed for wood consumption. Spatial analysis was performed to determine regions with similar annual wood consumption. The effects of seasons, weekdays and weekend days, and time of day on wood consumption were also analysed.

In addition to the domestic survey, wood burning diaries were sent out to determine the effect of temperature on wood consumption. An adjustment factor, which is a linear function of daily temperature, was derived to adjust wood consumption based on the average temperature of the day.

Results of the analyses were integrated with an emission modelling system, EMS-95, to estimate, spatially and temporally distribute the emissions.

Keywords: wood combustion, EMS-95, emissions inventory, Port Phillip Region, spatial allocation, temporal allocation

1. Introduction

Emissions inventories from various Australian airsheds show that wood combustion is a significant source of particulate emissions, particularly during winter (EPA 1995, EPA 1996a, EPA 1996b). Emissions from wood combustion for these inventories were usually spatially distributed according to population with an average per capita wood consumption applied over the whole airshed. Although seasonal variation was considered, emissions were estimated for only summer and winter. Also, day-to-day variation of emissions in a season was not considered even if the temperature varied greatly throughout the season.

In order to model emissions from wood combustion more accurately, EPA conducted a general domestic survey and a survey on daily wood use in the Port Phillip Region. The work was carried out as part of the Air Quality Improvement Plan for the Port Phillip Region (EPA 1997).

The general domestic survey obtained responses from more than 1600 households in the study region. It covered solid fuel combustion, lawn mowing, use of pleasure craft, waste incineration and barbecuing; however, only solid fuel (wood) combustion is discussed in this paper. Households were asked for their annual wood consumption, type of heater used, proportion of wood used in spring, summer, autumn and winter, and time the heater was used on weekdays and weekends.

In the daily wood use survey, households recorded their daily wood use in diaries. The wood burning diaries were completed by 272 households over a 2 week period in spring and another 2 week period in autumn. These periods were chosen as they had a larger variaton of temperature and wood use. The information in these diaries included the times when the fire was lit, the amount of wood used, the type of heater used (open fire, slow combustion etc) and other general household information. The information collected was related to average temperature of the days the woodheater was operated. The temperature data was collected from a number of EPA and Bureau of Meteorology stations in the study region.

The emissions inventory of the Port Phillip Region has been described in the report published by EPA (1998). This paper presents the results obtained from the surveys and explains the implementation of the results in the emissions modelling system EMS-95 (Emigh & Wilkinson 1997).

2. Domestic Survey

The domestic survey was conducted to find out the spatial, seasonal, weekday/weekend day and diurnal variations of wood use in the Port Phillip Region. Spatial analysis needed to be carried out to see whether there were distinct subregions in the study region.

Figure 1 shows the per household wood consumption in the local government areas (LGAs) of the Port Phillip Region. Although LGAs in the metropolitan area usually consumed less wood per household, there is no simple spatial pattern to group these LGAs into subregions. Hence, emissions from wood combustion were estimated on the basis of LGAs rather than subregions. LGAs which did not have enough responses for wood use in the survey were grouped with the neighbouring LGAs in the analysis.

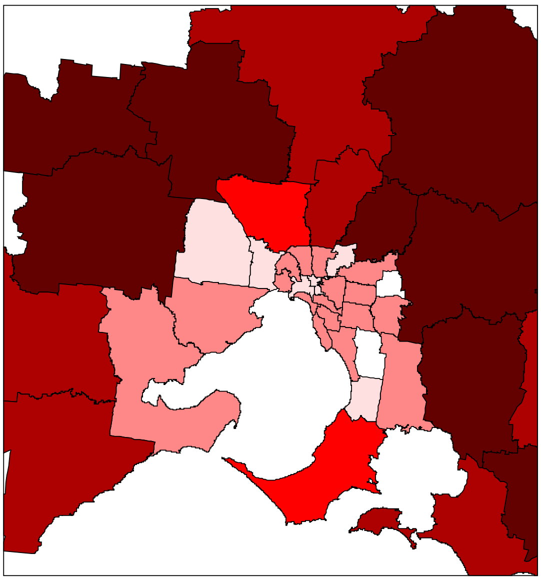

Figure 1 Wood consumption in the local government areas of the Port Phillip Region.

Figures 2-4 show the seasonal, weekday/weekend day and hourly variation of wood use in the Port Phillip Region obtained from the domestic survey. Nearly 70% of wood was consumed in winter. Note that wood use in spring was slightly higher than that in autumn, indicating that households were still habitually lighting fires in spring. It is a reflection of the transition to winter and people not yet being accustomed to the change in weather. There was little variation in wood use throughout a week, although the consumption on weekends was slightly higher. Through out a day, wood use was the lowest after mid-night and consumption gradually built up during the day and peaked at about 7 pm. The consumption dropped off rapidly after 10 pm.

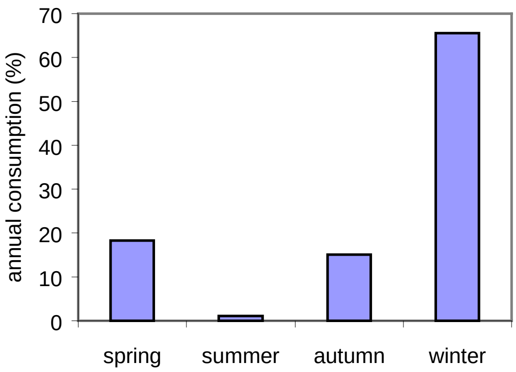

Figure 2 Seasonal variation of wood consumption in the Port Phillip Region.

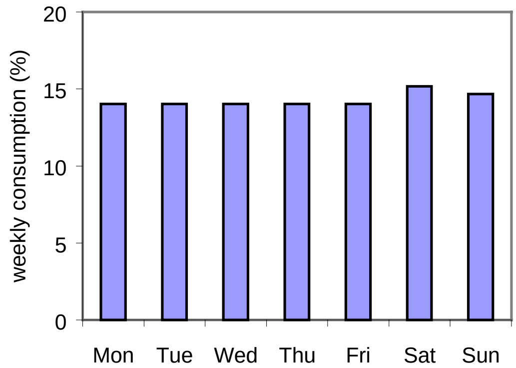

Figure 3 Weekday/weekend day variation of wood consumption in the Port Phillip Region.

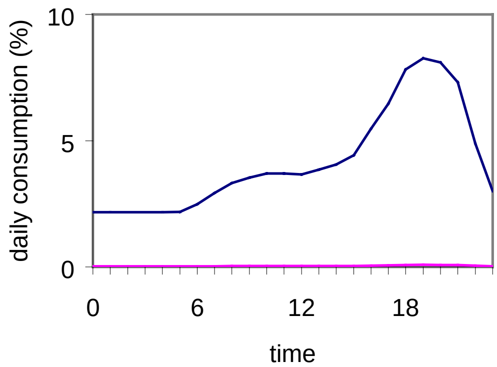

Figure 4 Hourly variation of wood consumption in the Port Phillip Region.

3. Wood Burning Diary

The wood burning diary was conducted to find out the relationship between wood combustion and temperature. The diary provided information regarding amount of wood used, hours that a fire was lit and proportion of households that lit a fire. Table 1 shows the correlation coefficients between these factors and average daily temperature. Days with less than five responses were excluded from the analysis. The table shows that the proportion of households that lit fires had the strongest relationship with average daily temperature. Wood use and number of hours that a fire was lit had poorer correlation coefficients as these factors were influenced by individual household circumstances as well. Figure 5 shows a plot of proportion of households that lit fires with average daily temperature. The proportion of households that lit fires was therefore chosen as the basis for adjusting emissions with temperature.

Table 1 Correlation coefficients between various factors and average daily temperature.

Factor	Correlation coefficient
wood use	-0.50
number of hours fire was lit	-0.53
proportion of households lit fires	-0.74

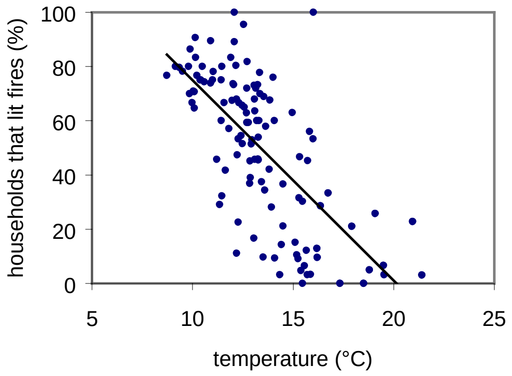

Figure 5 Relationship between proportion of households that lit fires and average daily temperature.

4. Implementation in EMS-95

EMS-95 is a emissions modelling system that spatially and temporally allocates emissions of photochemical and particulate species. The wood consumption that was used in EMS-95 was estimated by multiplying the number of households by the per household wood consumption in each LGA. Emissions were derived by multiplying the wood consumption in each LGA with emission factors (USEPA 1995). The emissions, which were estimated for a year, were allocated spatially to grid cells according to household distribution and temporally according to the following equation:

$$E_h = G \times M \times D \times H_h / W \quad (1)$$

where E_h is the hourly emission for hour h (kg pollutant/hr),
G is the gridded annual emission (kg pollutant/yr),
M is monthly temporal consumption factor,
W is weekly temporal consumption factor,
D is daily temporal consumption factor, and
H_h is hourly temporal consumption factor for hour h.

The monthly temporal factor was derived by dividing the seasonal consumption factor (see Figure 2) by 3. The weekly temporal consumption factor was the number of days in a month divided by 7. The daily and hourly temporal consumption factors were obtained from Figures 3 and 4 respectively.

Note that the above temporal factors were used for allocating annual emissions to each hour of a day without considering temperature variation. The relationship between the proportion of households that lit fires and average daily temperature as shown in Figure 5 was not a temporal factor and could not be used for allocating emissions. In order to implement the above relationship in EMS-95, it had to be converted into an adjustment factor where the emissions were adjusted up or down according to average daily temperature. An adjustment factor for wood combustion for a particular day could be obtained by dividing the number of households who lit fires on a particular day by the average number of households who lit fires in spring and autumn. Figure 6 shows the variation of the adjustment factor with the average daily temperature found in the survey.

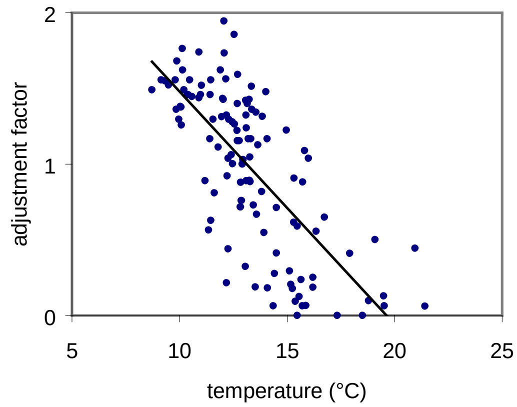

Figure 6 Variation of wood combustion adjustment factor with average daily temperature.

Note that the plot is exactly the same as Figure 5 except that adjustment factor is used instead of household that lit fires. The following linear equation was established from Figure 6 to find the adjustment factor for a given average daily temperature:

$$f = -0.1539 \times t + 3.0205, \; f > 0 \quad (2)$$

where f is the wood burning emission adjustment factor, and
t is the average daily temperature in °C.

If the adjustment factor calculated by the above equation was negative, the adjustment factor was set to 0.

The wood burning emission was then obtained by:

$$E_a = E_u \times f \quad (3)$$

where E_a is the adjusted wood burning emission estimate (kg pollutant/hr), and
E_u is the unadjusted wood burning emission estimate (kg pollutant/hr).

The adjustment factor was applied over the whole study region and should not be used for adjusting emissions due to regional difference in temperature. The proper method to account for regional difference in wood consumption is to conduct a domestic survey in the regions (see Section 2).

Figure 7 shows gridded emissions of PM_{10} (particulates less than 10 µm) in the Port Phillip Region obtained from EMS-95. Although metropolitan areas had lower per household consumption, emissions were still concentrated in them due to the larger number of households in these areas.

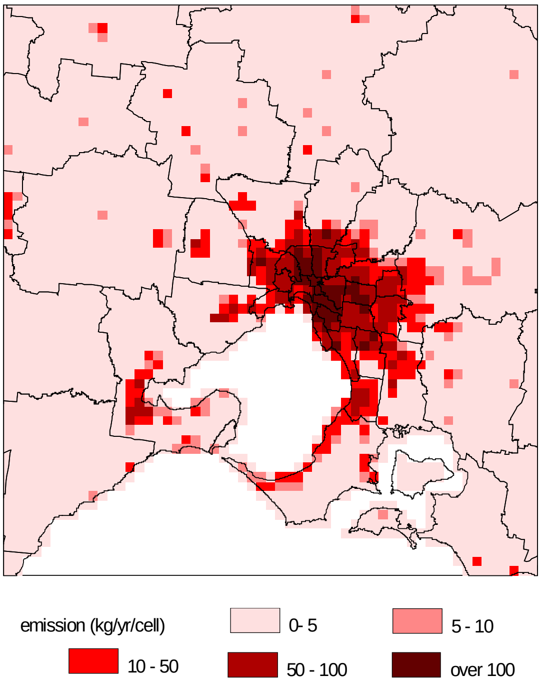

Figure 7 Annual emission of PM_{10} from wood combustion in the Port Phillip Region

5. Conclusion

Methods and factors were developed and applied successfully for spatially and temporally allocating emissions from wood combustion in the Port Phillip Region using EMS-95. Spatial distribution of emissions was based on different per household consumption in LGAs. Emissions were temporally allocated according to seasons (spring, summer, autumn and winter), weekday/weekend day and hours of the day. Emissions were also adjusted according to the average temperature of the day and this was the first time the effect of temperature was considered in estimating emissions from wood heater use .

The above methods assumed the spatial factor, temporal factors and temperature factor were independent. Investigation of the inter-dependence of these factors would require very large sample sizes for the surveys and was not carried out in this work. Nevertheless, the methods could easily be implemented in EMS-95 and would provide more accurate emission data for use in air quality modelling and air quality management than ever before. The results of this work will be used in the Air Quality Improvement Plan of the Port Phillip Region and the Australian Air Quality Forecasting System (Ng et al.), where different policy options, such as replacement of old heaters with heaters with emission reducing technology, will be tested for their effects on air quality.

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