Environmental Pollution 231 (2017) 367–378

Contents lists available at ScienceDirect

Environmental Pollution

journal homepage: www.elsevier.com/locate/envpol

Airborne ultrafine particles in a Pacific Island country: Characteristics, sources and implications for human exposure☆

C.F. Isley [a,*], P.F. Nelson [a], M.P. Taylor [a], M. Mazaheri [b], L. Morawska [b], A.J. Atanacio [c], E. Stelcer [c], D.D. Cohen [c], Anthony L. Morrison [a]

[a] Department of Environmental Sciences, Macquarie University, Sydney NSW 2109, Australia
[b] International Laboratory for Air Quality and Health, Institute of Health and Biomedical Innovation, Queensland University of Technology, Brisbane, 4000, Australia
[c] Centre for Accelerator Science, Australian Nuclear Science and Technology Organisation, Lucas Heights NSW 2232, Australia

ARTICLE INFO

Article history:
Received 2 March 2017
Received in revised form
19 May 2017
Accepted 6 August 2017
Available online 25 September 2017

Keywords:
Aerosol
$PM_{2.5}$
Ultrafine particles
Pacific islands
Fiji

ABSTRACT

The Pacific Islands carry a perception of having clean air, yet emissions from transport and burning activities are of concern in regard to air quality and health. Ultrafine particle number concentrations (PNCs), one of the best metrics to demonstrate combustion emissions, have not been measured either in Suva or elsewhere in the Islands. This work provides insight into PNC variation across Suva and its relationship with particle mass (PM) concentration and composition. Measurements over a short monitoring campaign provide a vignette of conditions in Suva. Ambient PNCs were monitored for 8 day at a fixed location, and mobile PNC sampling for two days. These were compared with PM concentration (TSP, PM_{10}, $PM_{2.5}$, PM_1) and are discussed in relation to black carbon (BC) content and $PM_{2.5}$ sources, determined from elemental concentrations; for the October 2015 period and longer-term data. Whilst Suva City PM levels remained fairly low, $PM_{2.5}$ = 10–12 μg m^{-3}, mean PNC ($1.64 \pm 0.02 \times 10^4$ cm^{-3}) was high compared to global data. PNCs were greater during mobile sampling, with means of $10.3 \pm 1.4 \times 10^4$ cm^{-3} and $3.51 \pm 0.07 \times 10^4$ cm^{-3} when travelling by bus and taxi, respectively. Emissions from road vehicles, shipping, diesel and open burning were identified as PM sources for the October 2015 period. Transport related ultrafine particle emissions had a significant impact on microscale ambient concentrations, with PNCs near roads being 1.5 to 2 times higher than nearby outdoor locations and peak PNCs occurring during peak traffic times. Further data, particularly on transport and wet-season exposures, are required to confirm results. Understanding PNC in Suva will assist in formulating effective air emissions control strategies, potentially reducing population exposure across the Islands and in developing countries with similar emission characteristics.

Suva's PNC was high in comparison to global data; high exposures were related to transport and combustion emissions, which were also identified as significant $PM_{2.5}$ sources.

1. Introduction

Suva is the most populous city of the Pacific Island Countries; located on a peninsula, in the southeast of Viti Levu, the largest of the Fiji Islands. With Fiji's population becoming increasingly urban, approximately 25% of Fiji's population, or 218,00 people (Government of Fiji, 2012) live in Suva. Public complaints data indicate that air pollution is a significant community concern for Fijians (Department of Environment Fiji, 2007), particularly vehicle emissions, burning of wastes and industrial emissions. Whilst $PM_{2.5}$ concentrations in Suva generally complied with the annual average World Health Organisation guideline of 10 μg/m^3 (World Health Organisation, 2006; Isley et al., 2017b); black carbon (BC) concentrations in Suva City were similar to much larger, more industrialised cities, and comprised 30% of $PM_{2.5}$ (Isley et al., 2017b). Statistical analysis of source contributions to Suva's $PM_{2.5}$, using

Abbreviations: ASP, aerosol sampling program $PM_{2.5}$ sampler; BC, black carbon; CF, correction factor; dp, ultrafine particle diameter; HVAS, high volume air sampler; PM, particulate matter, subscript numbers denote size fraction in μm; PMF, positive matrix factorisation; PNC, ultrafine particle number concentration; TSP, total suspended particulate.

☆ This paper has been recommended for acceptance by Eddy Y. Zeng.

* Corresponding author.
E-mail address: cynthia-faye.isley@students.mq.edu.au (C.F. Isley).

http://dx.doi.org/10.1016/j.envpol.2017.08.021

elemental concentration data, show that 42%–48% of $PM_{2.5}$ originates from combustion sources: including diesel burning by small ships, industry and for power generation; open burning of wastes; road vehicle emissions and heavy fuel oil combustion by large ships (Isley et al., 2017a). Combustion emissions are a source of fine ($PM_{2.5}$ mass concentration of particles with aerodynamic diameter < 2.5 μm) and ultrafine aerosol (diameter < 0.1 μm); and diesel emissions are typically characterised by particles in the ultrafine size range (Kittleson et al., 2004; Ning et al., 2013). The prevalence of diesel combustion emissions in Suva (Isley et al., 2016) indicates the likelihood of elevated PNCs.

Whilst many aerosol health-risk studies have focused on $PM_{2.5}$, ultrafine particles may present a greater health risk. In a review of the potential exposure routes and health risks of ultrafine particles, Chen et al. (2016) concluded that ultrafine particles play a major role in adverse impacts on human health and are likely responsible for many of the health impacts currently attributed to $PM_{2.5}$. Ultrafine particles have large surface area per unit mass and are comparable in size to the cellular structure of the lungs (Loxham et al., 2015); transporting to the brain and other organs (Frampton and Rich, 2016). This makes them potentially harmful to human health; particularly when composed of black carbon (Donaldson et al., 2001), diesel exhaust particles (Srivastava and Yadav, 2016) or organic compounds (Akhtar et al., 2014). Ostro et al. (2015) reported significant positive associations between ultrafine particle components (elemental carbon, metals and mobile sources) and ischemic heart disease. Ultrafine particles have been related to adverse cardiac (Holland et al., 2017), vascular (Karottki et al., 2015) and lung function (Samoli et al., 2016) effects, markers of inflammation and diabetes (Karottki et al., 2014) and to brain function impairment (Allen et al., 2014; Cheng et al., 2016; Solaimani et al., 2017).

Whilst very limited research has been conducted addressing air quality in the Pacific Islands, it is apparent that all Pacific Island countries share similar air quality concerns to Suva (Fiji). Monitoring of PM_{10} has been carried out in Noumea, by L'Association de Surveillance Calédonienne de Qualité de l'Air (Escoffier et al., 2016), as well as limited $PM_{2.5}$ analysis (Gleye, 2010). Whilst no quantitative source apportionment data are available for Noumea, the primary source implicated for episodes of elevated PM was the burning of diesel oil at the Doniambo thermal power and nickel processing plant; other elevated PM_{10} occurrences in Noumea were attributed to road traffic, burning and construction (Escoffier et al., 2016). The dependence on diesel fuel combustion for energy is common across the Pacific Islands (Dornan and Jotzo, 2012; Keruring van Elektrotechnische Materialen te Arnhem, 2012; Pacific Energy Summit, 2013; Taibi et al., 2016). Further to this, the burning of biomass on a household level, for cooking purposes and disposal of household or agricultural wastes, is also a concern with regard to air quality across the Pacific Islands as it is in other developing countries of Asia, Africa and South America (Thaman et al., 2003; Periathamby et al., 2009; Mataki, 2011; Owens et al., 2011; Wiedinmyer et al., 2014; Isley et al., 2017a). The authors are not aware of any studies conducted in Pacific Island countries investigating PNCs and, considering their potential public health implications, this is an area that requires research.

In light of the above, the aim of this paper is to address the lack of quantitative and scientific knowledge on ultrafine particle characteristics in the Pacific Islands through a case-study of Suva. This study provides a vignette of PNCs in Suva's air, both ambient levels and for various microenvironments, as well as their relationship with PM concentrations and sources. Ultimately this research seeks to demonstrate whether elevated PNCs are present, and to indicate where further investigation of PNCs may be warranted. The perception of Suva and other Pacific Island cities is that, as the islands are small and isolated, with strong ocean winds and relatively low human populations, the PNCs would be low. This study aims to test this assumption and inform a future policy course regarding action on ultrafine particle air quality in the Pacific Islands.

2. Method

2.1. Study design

Particulate matter in terms of mass concentration of total suspended particles (TSP), PM_{10}, $PM_{2.5}$ and PM_1; PNC and mean particle diameter (dp), were recorded at a fixed-site monitoring station: the Suva City site (see Graphical Abstract) over an eight day period, from 20th to 27th October 2015. At the City site, equipment was affixed approximately 18 m above the street level, to a tower on top of a four-level office building on the west coast of the Suva peninsula. This same site is used by the Australian Bureau of Meteorology (Australian Government, 2016) to collect hourly-averaged air temperature, wind speed and wind direction data. Data collected at this site also include gravimetric $PM_{2.5}$ samples, for a period of one year, including the October 2015 period; analysed for BC and elemental concentration. Air particulate sources, determined using positive matrix factorisation for elemental concentrations, are also available. This location was therefore useful for interpretation of the PNC and PM concentration and characterisation of particulates in the Suva airshed. Being located on the western side of the Suva peninsula, air sampled at this site has travelled over the land and city area of Suva. The Suva bus terminal, city markets, an industrial precinct and shipping port activities all lay within 1 km of this Suva City site.

Mobile measurements of PNC and dp were collected whilst outdoors and commuting by different methods: walking, bus, taxi and private car. On the 19th and 20th October 2015, 8 h of measurements (16 s averages) were collected across Suva. The instrument used for this collection, the Nanotracer (described below), allows markers to be placed in the data by the press of a button on the instrument. Each time a marker was activated, the marker number, relevant location, activity and other relevant factors were noted in a log-book, along with the time, for later addition to the data file. The microenvironments visited are summarised in Table 1. Locations sampled include Kinoya, Centrepoint, Flagstaff, Suva City and Suva Point, as well as travel in-between these locations. Kinoya is a residential suburb located in the most densely-populated council area of Fiji (Nasinu). Centrepoint is a busy traffic area on the intersection of two main roads, comprising two shopping centres. Flagstaff is also a busy traffic area, with the intersection of roads from the city, Suva's northern suburbs and the University of the South Pacific to the east. Suva Point receives mainly ocean winds; although the road west of Suva Point (towards Flagstaff) is a busy thoroughfare for university traffic. Suva City is the centre of economic and transport activity, featuring the central bus terminal for the region. During mobile measurements, the Nanotracer was worn on a belt, with a sampling tube attached to the shirt collar, as to gain measurements indicative of the air in the breathing zone. During data collection, time, location and mode of transport were noted, along with whether measurements were taken near a road (compared to within a property); and whether windows of vehicles were open or closed. GPS location was also logged every 16 s; using the Greenalp real time tracker (https://www.greenalp.com/RealTimeTracker/) on a mobile telephone, recording spatial coordinates for each Nanotracer measurement and enabling mobile paths to be mapped (Graphical Abstract).

Cloud cover data were also used in order to determine atmospheric stability and mixing height. Cloud cover data for the