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Identification and characterization of inland ship plumes over Vancouver, BC

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Abstract

There is increasing concern regarding the impact of marine vessel emissions on the air quality of coastal areas and their relative impact is increasing as emissions from other sources decrease and shipping activities increase. Marine vessels contain a variety of large diesel engines and in a relatively large number of areas they are currently not restricted from using fuels with a high sulphur content.

In August 2001 during the Pacific 2001 study, which included the port city of Vancouver, British Columbia, a large suite of gas and particle measurements were obtained with high time resolution. Among a total of 29 SO_2 episodes observed >5 km inland during a period of 15 days, eight were caused by local emissions sources and four were identified as relatively fresh ship plumes. These ship plumes were indicated by an increase of SO_2 above 9 ppbv typically lasting for a few hours. They were accompanied by increases in NO_x, NO, CO, VOCs, particle counts (5–200 nm), black carbon and $PM_{2.5}$. Only one plume occurred when an Aerodyne aerosol mass spectrometer (AMS) was in operation and this event is studied in detail. Ultrafine (<100 nm) sulphate was one of the most unique features of this plume, which also contained significant amounts of ultrafine particulate organic matter. The distribution of AMS organic mass fragments for this case strongly resembled those measured directly in the effluent of an ocean-going ship, suggesting a signature for marine diesel engine emissions. During the event studied in detail, which occurred at night, the meteorological measurements indicated the same plume or puff of high concentrations moved over the measurement site on two instances with peak concentrations separated by about 3 h. From the first to the second occurrence all species decreased in concentration except particle sulphate and VOCs. This is considered to be direct observation of nighttime gas-to-particle conversion of SO_2. This process was likely facilitated by SO_2 dissolving into the wet surface of particles given the high humidity observed on that night.

Keywords: Ship emissions; Particulate matter; Urban air quality; Formation of sulphate; Sulphur in diesel fuel; Ship plume; Aerosol mass spectrometer

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1. Introduction

In coastal areas there is increasing concern regarding the contribution that marine vessels make to poor air quality. At many ports, ship traffic is increasing while the emissions from other sources, such as industry and motor vehicles are decreasing. The Straight of Georgia and the port areas around Vancouver, BC, are busy with ship traffic associated with many activities. These include large cargo ships involved in trade within the Pacific Rim, cruise ships and ferry boats. In addition, ship traffic from trade with the Asian continent is projected to dramatically increase in the coming decades, which could lead to significant degradation in air quality if emissions are not regulated more effectively.

During the Pacific 2001 field study, an intensive ground-based measurement site was centrally located inside the limits of Vancouver to examine the characteristics of the urban air mass containing fresh emissions of gaseous and particulate pollutants and to obtain data potentially relevant to population exposure. At this site, referred to as Slocan Park (Slocan), which is at least 4 km inland, several short term peaks in SO_2 were observed during the 15-day period of measurement. Some of these peaks are hypothesized to be related to relatively intact ship plumes. The goal of this paper is to examine these peaks more closely in order to determine if ships were responsible and subsequently to document the characteristics of such plumes.

According to the Greater Vancouver Regional District (GVRD) emissions inventory, 19,000 mt of SO_2 are emitted annually within the Lower Fraser Valley (Policy & Planning Department, GVRD, 2002). Of this total, 54% occur in Whatcom Country, Washington, and are thus, not of local origin relative to Slocan Park. The petroleum and metal processing industries are the dominant sources of SO_2 (9500 mt) in the LFV and 86% of this is from Whatcom County. The other 14% are mainly from sources within the greater Vancouver area, including refineries in relatively close proximity to Slocan. Overall, marine activity is estimated to emit 6100 mt of SO_2, of which about 83% occurs from ships operating over waters considered to be within the GVRD (i.e., Canadian waters). Marine emissions are thus estimated to be the largest single SO_2 source sector in the GVRD. The paper and allied products industries account for an insignificant amount (0.3%) of the total SO_2 emissions in the LFV. Rail and on-road traffic also play a relatively minor role.

The measurements at Slocan showed that the larger SO_2 excursions were most likely linked to local sources, either ships or refineries. The ship emissions were typically accompanied by higher NO concentrations compared to the refineries. There were also differences in the wind directions bringing pollutants from these two sources to Slocan. In addition to elevated SO_2 concentrations, the most distinct features of the ship plumes were greater concentrations of 30–100 nm particles and much greater concentrations of some trace-level volatile organic compounds (VOCs). Particles from the ship emissions were mainly composed of unsaturated organic species, similar to other diesel emissions. However, there was also a greater amount of very small sulphate particles in the ship emissions compared to the local traffic and to the urban background particles. The ultimate origin of this sulphate was the sulphur in the marine diesel fuel leading to primary sulphate (pSO_4) emissions and/or secondary sulphate formed during transport to Slocan from the primary SO_2 emissions. The formation of ultrafine pSO_4 during combustion has been shown to be dependant on fuel sulphur content (Schneider et al., 2005).

2. Data

2.1. Measurement site

Slocan Park (49°12'39 N, 123°2'51W) is centrally located within the greater Vancouver area (Fig. 1) with significant populations residing in all directions from the site. It is 92 m above sea level and elevations decrease noticeably towards the north and west. The park is an open area of about 100 m × 300 m with mature trees and single-family homes around the perimeter. English Bay is about 8 km to the northwest and the open part of the Strait of Georgia is 15 km west. Burrard Inlet is in a northerly direction and the North Arm of Fraser River is towards the south. At their closest points they both are about 4 km away from Slocan Park. Fig. 1 shows the location of Slocan Park on a map of Vancouver.

2.2. Air pollutant measurements

A relatively large suite of both gaseous and particulate measurements was obtained during the