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Examination of pollution trends in Santiago de Chile with cluster analysis of PM_{10} and Ozone data

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Abstract

Because of the high levels of pollution that Santiago de Chile experiences every year in winter, the government has set up an air quality monitoring network. Information from this network is employed to alert people about the quality of air and to enforce several control strategies in order to limit pollution levels. The monitoring network has 8 stations that measure PM_{10}, carbon monoxide (CO), sulphur dioxide (SO_2), ozone (O_3) and meteorological parameters. Some stations also measure nitrogen mono- and dioxide (NO_x), fine particles ($PM_{2.5}$) and carbon. In this study we have examined the PM_{10} and O_3 data generated by this network in the year 2000 in order to determine the seasonal trends and spatial distribution of these pollutants over a year's period. The results show that concentration levels vary with the season, with PM_{10} being higher in winter and O_3 in summer. All but one station, show a peak in PM_{10} at 8:00 indicating that during the rush hour there is a strong influence from traffic, however, this influence is not seen during the rest of the day. In winter, the PM_{10} maximum occurs at 24:00 h in all stations but Las Condes. This maximum is related to decreased wind speed and lower altitude of the inversion layer. The fact that Las Condes station is at a higher altitude than the others and it does not show the PM_{10} increase at night, suggest that the height of the inversion layer occurs at lower altitude. Cluster analysis was applied to the PM10 and O_3 data, and the results indicate that the city has four large sectors with similar pollution behavior. The fact that both pollutants have similar distribution is a strong indication that the concentration levels are primarily determined by the topographical and meteorological characteristics of the area and that pollution generated over the city is redistributed in four large areas that have similar meteorological and topographical conditions.

Keywords: Particulate matter; Ozone; Cluster analysis

1. Introduction

The high levels of pollution that are observed in many large cities of the world have well documented consequences for human health (Lee et al., 2000; Dockery et al., 1997). Santiago has high levels of

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pollution throughout most of the year, with high PM_{10} levels in winter, and high O_3 levels in summer. It is common to observe an increase in the number of children's hospitalizations due to respiratory diseases following a pollution event in winter to (Ostro et al., 1999; Sanhueza et al., 1999), even an increase in daily mortality was observed (Cifuentes et al., 2000; Ilabaca et al., 1999). Particle mass concentration (PM_{10}) averages near 300 $\mu g\,m^{-3}$ are frequent in the western part of Santiago (Pudahuel, Cerrillos). Some isolated events of 500 $\mu m\,m^{-3}$ or more occur several times during winter (Jorquera et al., 1998; Perez et al., 2000; Artaxo et al., 1999). Another effect that contributes to the high particle levels observed in winter is the temperature inversion. The height of the inversion layer during winter could be as low as 300 m at night and early morning (Gramsch et al., 2000), in summer, it reaches 2000–3000 m (Rutland and Garreaud, 1995). Ozone is a secondary pollutant and its concentration depends on the concentration of primary pollutants (NO_x, VOC) and the intensity of solar UV radiation, thus ozone concentration is high during summer. Ozone hourly maxima reach concentrations levels between 100 and 150 $\mu g\,m^{-3}$ with some isolated events as high as 320 $\mu g\,m^{-3}$ in the eastern part of the city (Las Condes) which is located downwind from the center of the city. The Chilean norm for ozone is 160 $\mu g\,m^{-3}$ hourly maximum; however this norm is exceeded more than 140 days per year.

Because of the potential health effects associated with elevated levels of PM_{10} and Ozone, the government developed a number of control strategies to help reduce pollution. In 1994, the "Environmental-Base Law" (Conama, 1994) was passed and directed the National Commission for the Environment (Conama) to develop a pollution-control plan for Santiago and its surroundings. This plan,—which was completed on July 1, 1997—, provided the framework for the decontamination effort in Santiago. The Plan established specific emission reduction targets for the most common pollutants such as particulate matter with aerodynamic diameter $<10\,\mu m$ (PM_{10}), ozone (O_3), nitrogen oxides (NO_x), sulphur dioxide (SO_2) and carbon monoxide (CO). The Plan also provides the legal framework to enforce the control strategies needed for the pollution reduction efforts in Santiago (Conama, 1997). The first strategies implemented in the early 1990 were directed towards removing fixed sources like diesel electric generators, waste burning, and large wood and coal heaters. Afterwards, the quality of the public transportation buses was improved, all new cars were required to have catalytic converter, and many streets were paved. Currently, the efforts are directed towards improving the public transportation and reducing the number of private cars used in the city. However, nothing has been done to reduce pollution from kerosene and wood burning for house heating.

An important part of the plan was to set up a network of eight monitoring stations (Macam network) distributed around the city and operated by the Ministry of Health. In 1995, five monitoring stations were located near the center of the city. Later it was determined that this arrangement did not cover areas with high pollutant levels and most contamination events (days with high average PM_{10} levels) were not detected. In 1997, new stations were added and some were closed. The new configuration has eight stations distributed across the city that measure PM_{10}, O_3 and CO on an hourly basis.

Table 1
Years of operation, pollutants measured and altitude over sea level for the monitoring stations of the Macam network

Station	Las Condes	Providencia	La Paz	Parque O'Higgins	La Florida	Pudahuel	El Bosque	Cerrillos
First year of operation	1988	1988	1988	1988	1997	1997	1997	1997
CO	X	X	X	X	X	X	X	X
SO_2	X	X	X	X	X	X	X	X
O_3	X	X	X	X	X	X	X	X
NO_X/NO_2	X	Until 1996	—	Until 1996	—	X	—	X
PM10	X	X	X	X	X	X	X	X
PM2.5	X	—	—	X	X	X	—	—
Height (m)	700	550	530	500	500	480	470	470

X, contaminant being measured, —, not measured.