Nature Environment and Pollution Technology
An International Quarterly Scientific Journal

ISSN: 0972-6268	Vol. 11	No. 2	pp. 181-186	2012

Original Research Paper

A Semi-Empirical Method of PM-10 Atmospheric Pollution Forecast at Santiago De Chile City

Raul G. E. Morales, Augusto Llanos*, Manuel Merino* and Claudio H. Gonzalez-Rojas**
Centro de Ciencias Ambientales, Facultad de Ciencias, Universidad de Chile, Santiago, Chile
*Centro Nacional del Medio Ambiente (CENMA), Universidad de Chile, Santiago, Chile
**Departamento de Quimica, Facultad de Ciencias, Universidad de Tarapaca, Arica, Chile

Nat. Env. & Poll. Tech.
Website: www.neptjournal.com
Received: 5/12/2011
Accepted: 6/2/2012

Key Words:
Santiago de Chile city
Urban atmospheric pollution
PM-10 forecast
Relative humidity

ABSTRACT

Santiago de Chile city, localized in the west side of the Andes Mountain (550 m.s.l.), South America, every year presents high levels of atmospheric pollution by PM-10 in autumn-winter periods. Therefore, forecast model research is a subject of high public interest in order to develop useful and appropriate tools for health impacts prevention on the population. In this work, we present a PM-10 atmospheric pollution semi-empirical forecast method developed from a singular behaviour observed on the relative humidity trends detected in Lo Prado Hill meteorological station previous to critical episodes of urban atmospheric pollution by PM-10. This meteorological station is localized at the top of the coastal mountains (1035 m.s.l.), in the west side of the city. From systematic observations between 1998 and 2006 in this particular meteorological station, we have detected how the relative humidity follows a typical descendent behaviour when a type A synoptic weather condition arrives to central Chile and induces a PM-10 pre-emergency episode of urban atmospheric pollution. Our semi-empirical method is based on a sigmoidal behaviour of the relative humidity as a time function, observed in this meteorological station under a type A synoptic weather condition. We have confronted the present forecast method to different pre-emergency critical episodes occurred in the city between 1999 and 2006. Our results are amazing due to these pre-emergency episodes can be predicted at least by 34 hours before to the PM-10 pollution concentration reaches the maximum peak at the city. Contrarily to this specific station, the remainder eight stations localized in the surface of the city are not able to describe this particular phenomenon.

INTRODUCTION

It is well known through the World Health Organization that Santiago de Chile city in autumn and winter time is one of the most polluted metropolitan areas of the world by PM-10 due a combination of geographical and meteorological factors (Morales 2006, Sandoval et al. 1993). The city is located to the west side of the Andes Mountains (520 m.s.l. and 33.5°S, 70.8°W), on a moderate slope defined by the hydrographic basin of the Mapocho and Maipo rivers and parallel to the east side of the coastal mountain, 100 km faraway to the Pacific ocean by the west. At this subtropical latitude the subsidence temperature inversion controls the vertical exchange air during most of the year. Therefore, the lowering and strengthening of the inversion during the occurrence of coastal lows has been related to forced subsidence down the Andean slope favoured by the surface convergence at the leading edge of those wavelike disturbance propagating from north to south of central Chile (Rutlland & Garreaud 1995).

Since 1998 the city government has implemented a systematic urban atmospheric environmental monitoring program by means of an air quality and meteorological stations network according to the present distribution in the city (Fig. 1). Furthermore, every year, since March to August, the city implements a daily forecast system based on a 24 hours potential meteorological factor (Casmassi 1999).

On the other hand, this network has permitted to characterize the PM-10 concentrations through the year and generate the air quality inventory database for the control and applications of the public regulations in this subject. It is well known fact that there are health impacts due to air pollution (Dockery et al. 1993), where PM-10 has acute and chronic effects related to minor upper respiratory irritation to chronic respiratory and heart disease, lung cancer, acute respiratory infections in children and chronic bronchitis in adults, aggravating pre-existing heart and lung disease, or asthmatic attacks. In addition, short and long-term exposures have also been linked to premature mortality and reduced life expectancy (Kampa & Castanas 2008).

Moreover, Santiago de Chile, as an urban centre, is expanding rapidly, leading to the growth of megacity, which is defined as a metropolitan area with population exceeding

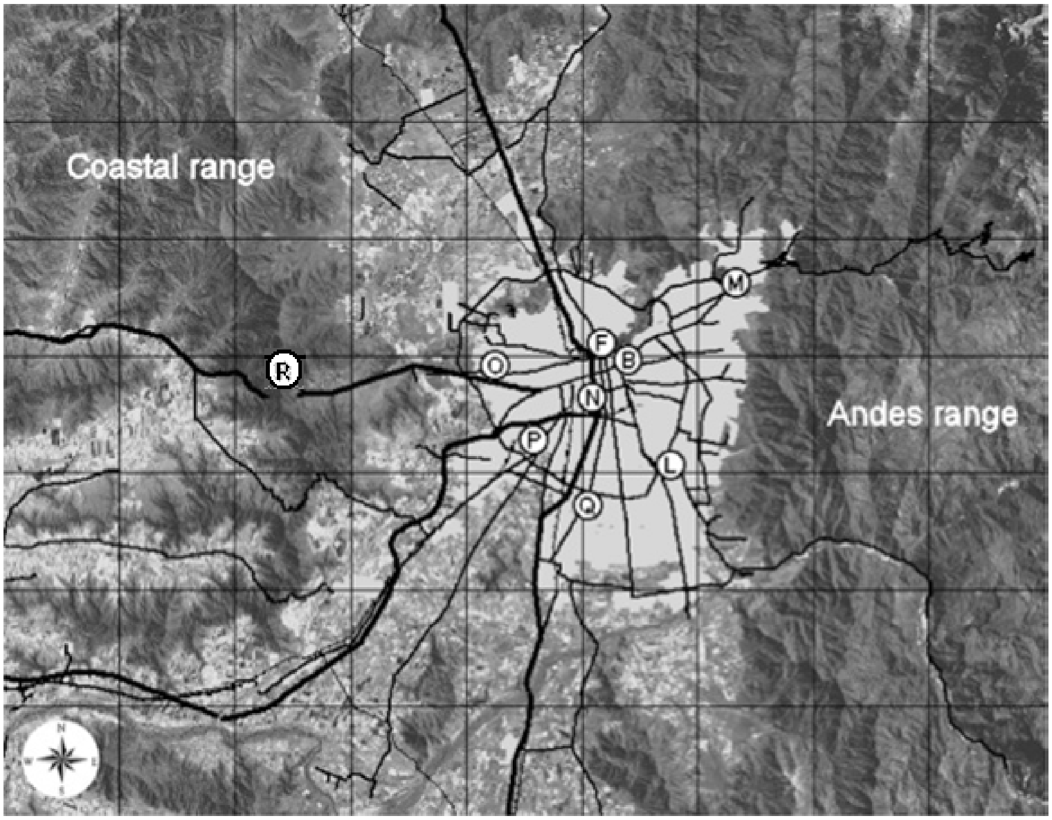

Fig. 1. City of Santiago and its regional topography. Grey area is the urban region and the black lines represent the main routes and streets (10 km grid lines). White dots designate the air quality monitoring stations of the MACAM-2 network (M: Las Condes, B: Providencia, F: La Paz, N: Parque O´Higgins, L: La Florida, O: Pudahuel, P: Cerrillos, Q: El Bosque, R: Lo Prado).

the six million inhabitants. Under this situation the people are beginning to experience the same air quality conditions of other megacities in the world (Leiva et al. 2004, Molina & Molina 2004).

The Air Quality Chilean Normative 1998 determines different preventive considerations to the population activities according to the following limits for PM-10 concentration on a 24 hours average basis: from 195 to 239 µg/m^3 determine an alert level; from 240 to 329 µg/m^3 is defined the pre-emergency level, and 330µg/m^3 and higher is defined as emergency level.

This last level only has had two episodes in a decade, while in the same period the pre-emergency episodes were 41 and the alert episodes were 86. From this database 2010, that includes the eight surface stations of air quality network of the city, the same statistical analysis determines the Pudahuel station, localized into the west side of the city, as the main focus of PM-10 air pollution critical episodes, registering over the 75% of them.

Therefore, particulate matter pollution forecast models merge as a significant tool in order to prevent on time the population risk due to specific working and entertaining activities under critical episodes of urban atmospheric pollution.

MATERIALS AND METHODS

The meteorological data were obtained by Met One and Vaisala instruments, whereas the relative humidity was measured by a Humicap 180 equipment between 100% to 0.8% (± 3%). The PM-10 concentration were measured by a TEOM 1400a, Rupprecht & Patashnic Co., Inc. at 60°C, following a standard calibration and validate data from SESMA, a Metropolitan Service of the Chilean Health Minister.

RESULTS AND DISCUSSION

Meteorological characterizations of the central zone of Chile, where Santiago city is localized, have determined the main synoptic weather conditions, type A and type BPF episodes (Rutlland 1994). From these weather conditions, the most frequent one, type A, corresponds with the typical onset of a coastal-low after a frontal disturbance has moved northwards in its dissipating stage. Therefore, this surface meteorological

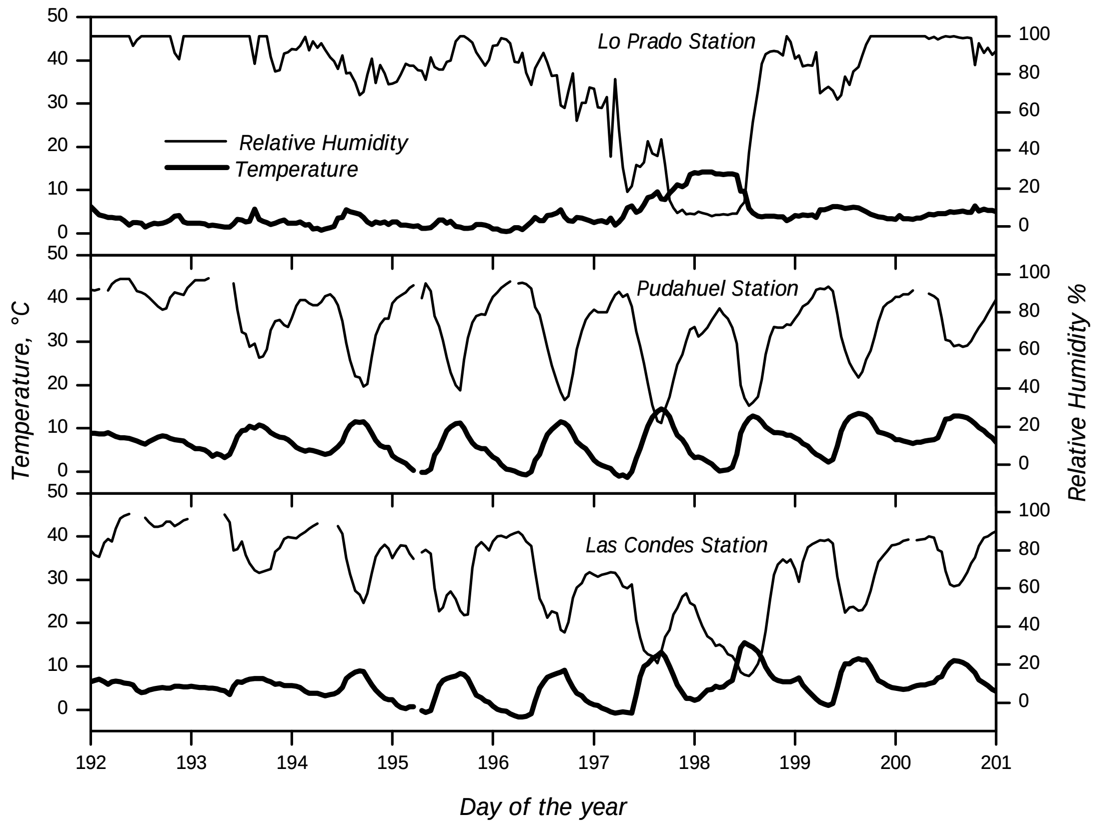

Fig. 2: A typical pattern of the relative humidity and temperatures at local level observed in Lo Prado Hill station, Pudahuel and Las Condes stations localized in the surface of the city. The figure shows a PM-10 critical episode occurred in June 17, 1999.

condition can be well characterized by a coastal through between a reinforced southeastern subtropical anticyclone and a migratory cold high over Argentina. As the coastal low passes over, clear and warm-dry conditions with a depressed subsidence inversion base prevail, ahead of the centre of the low, as the surface atmospheric pressure drops a few hPa. Fast changes in the zonal wind component seem to anticipate the onset and fill-up stages of coastal lows at about 900 hPa level (Rutlland & Garreaud 1995).

Therefore, Lo Prado Hill station, installed at an altitude of 1035 m, on a saddle point of the coastal range near 30 km west of downtown Santiago city, follows a singular and characteristic temperature and relative humidity pattern induced by a type A synoptic weather condition before than the remainder stations, 500 m down respect to Lo Prado station, can detect the same trends (Fig. 2). Particularly, we have observed the pre-eminence of a PM-10 critical episode in Pudahuel station in the east side of the city, near to the coastal mountain when the relative humidity in Lo Prado Hill station falls down to lower than 50% (Fig. 2).

On the other hand, in Lo Prado Hill station we have observed that the relative humidity as function of time generally can be fitted to sigmoidal curve (Fig. 3). This singular behaviour, detected on an empirical basis, determines the origin of our mathematical model because the type A synoptic weather conditions need to reach a determined intensity in order to initiate a PM-10 critical episode in the city, and the relative humidity define a natural clock when this parameter falls down lower than 60%.

Furthermore, from every data set under analysis by the period 1998-2006, the relative humidity level falls down from near 100% to under 20% in something more than 48 hours, while this parameter reaches the lowest, simultaneously, the PM-10 concentration in the surface of the west side of the city, due to a bad ventilation of the local air mass, reaches a maximum value some hours later (Fig. 4). As can be seen in this figure, the relative humidity follows a typical behaviour pattern previous to initiate a PM-10 pre-emergency critical episode observed in the city under a type A synoptic weather conditions. Furthermore, the local meteorology data in Pudahuel show that how the humidity increases and the temperature decreases in a contrarily way to Lo Prado Hill trends. These last factors explain the favourable physico-chemical conditions to increase

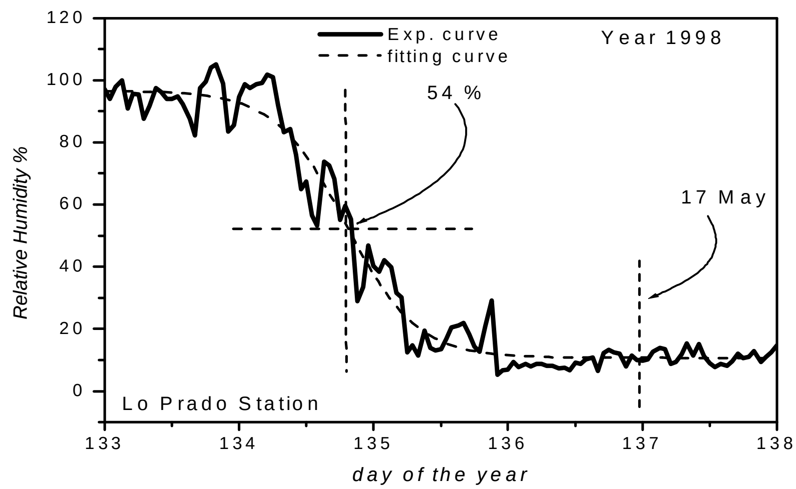

Fig. 3: A sigmoidal function of the relative humidity at Lo Prado Hill, through to four days before to the critical episode of PM-10 at Pudahuel zone of Santiago de Chile occurred in May 17, 1998, before to reach the maximum concentration.

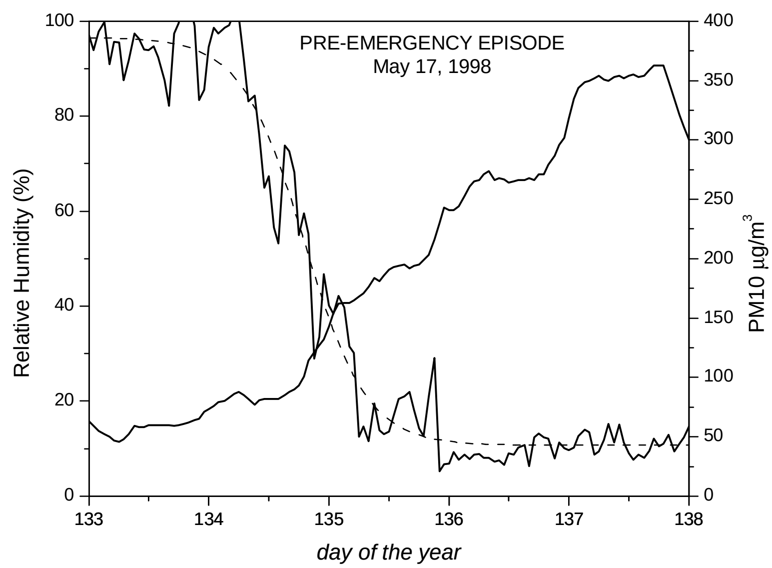

Fig. 4: Relative humidity at Lo Prado Hill four days before to the critical episode of PM10 at Pudahuel zone of Santiago de Chile occurred in May 17, 1998.

secondary particulate matter in Pudahuel zone respect to other places of Santiago city (Toro 2010, Seguel et al. 2009).

Therefore, based in this empirical behaviour, we have observed the feasibility to generate a forecasting method for PM-10 critical episode of concentration maximum by means of a simple sigmoidal mathematical function that describes the relative humidity trend induced by an type A weather synoptic condition in the Lo Prado Hill station, because after the middle point of the sigmoidal function the PM-10 concentration follows a straight forward way to the maximum concentration (Fig. 4).

In this case, a sigmoidal fitting of the experimental data of the first part of the curve, before to arrive to the middle point, permits to define the best curve of the relative humidity as a time function, as can be seen in our case under study presented in Fig. 4. When we have arrived to the middle point of the curve, we can define a standard time range given by the best sigmoidal fitting between the middle point and the bottom of the curve. Thus, we have found a forecast method based on the relative humidity for a type A synoptic weather condition every time that this physical factor in Lo Prado Hill station falls down to 60%, because the same weather condition is initiating a critical episode of PM-10 in the Pudahuel station at the city. From this last circumstance our semi-empirical sigmoidal curve merges as a simple but

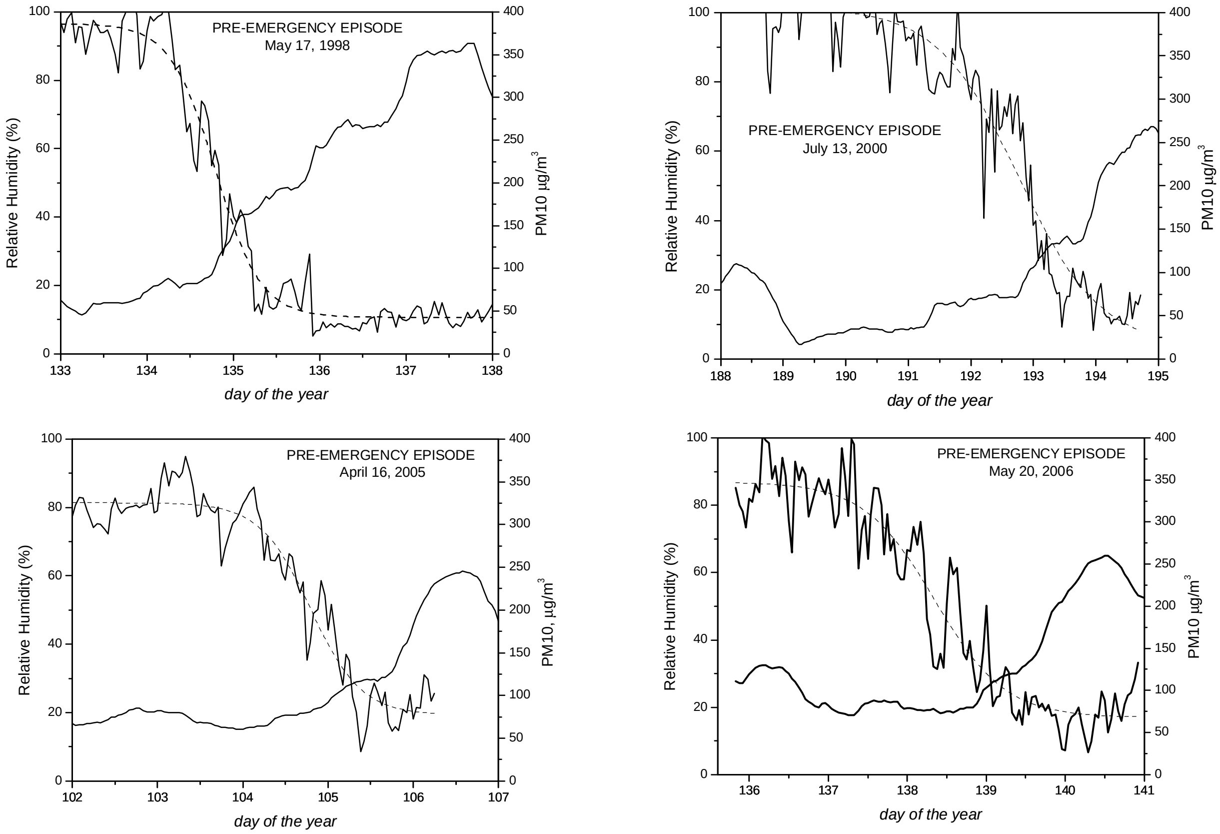

Fig. 5: Typical relative humidity profiles in Lo Prado Hill station and pre-emergency critical episodes of PM-10 in Pudahuel station at the Santiago de Chile city.

significant forecast method, because it permits us to predict the remainder time that the relative humidity will take to reach its lowest limit, predicting an estimated position time of the PM-10 concentration maximum in Pudahuel station.

Fig. 5 shows four of the 41 pre-emergency critical episodes detected between 1998 and 2006. We have chosen to show the most typical profiles in this period, where the figure present in each ordinate the relative humidity at Lo Prado Hill station and the PM-10 concentration at Pudahuel station, while in the x-axis the time period where these critical episodes occurred. It must be considered that the PM-10 concentrations correspond to the mobile average of the last 24 hours measurements determined every hour, according to the Chilean regulation (AQChN 1998).

In all cases under study, a sigmoidal curve can be fitted where the middle points were found near to 52% of the relative humidity (Table 1). The time range positions between the maximum relative humidity and the middle point of the sigmoidal curve permit us to predict, in a symmetric way, the corresponding time to be ascribed to the minimum relative humidity.

This last value can be considered as minimum time necessary in order to expect the critical episode of PM-10 concentration when this parameter becomes a maximum at the Pudahuel station. In the four cases presented in Table 1, we have found a minimum time range prediction of 40 ± 6 hours. This time permits us at least to present a new criterion for high pollution forecast of critical episodes of PM-10 at Santiago de Chile city.

The present semi-empirical method has a particularity that makes it more reliable when we are able to incorporate additional relative humidity data after the middle point. The curve fitting improvement obviously increases point by point if we extend the range near to the final part of the sigmoidal function, however, it must be considered that while the forecast method increase its exactitude at the same time decrease the time range prediction capacity.

Nowadays, based on a meteorological potential analysis, the city presents a single 24 hours forecast method for critical episode of PM-10 (Casmassi 1999). Our forecast method, based on this semi-empirical approach to the relative humidity behaviour at 1000 m of altitude, would permit

Table 1: Pre-emergency critical episodes of PM-10 occurred in Pudahuel station at Santiago de Chile city.

Year	Date of the critical episode	Synoptic Meteorological Condition	Relative Humidity* at the middle point of the sigmoidal curve (%)	Standard time range prediction ** (hours)
1998	May 17	Type A	54	31
2000	July 13	Type A	52	42
2005	April 16	Type A	52	39
2006	May 20	Type A	52	46
Average data				40±6

* Relative humidity determined at Lo Prado Hill station.
** Standard time range between the middle point and the bottom of the sigmoidal curve.

us to predict a critical episode of PM-10 generated by a type A synoptic weather condition at least 34 hours before.

ACKNOWLEDGEMENT

The authors acknowledge the financial support by Centro Nacional del Medio Ambiente (CENMA) and the Centro de Ciencias Ambientales de la Universidad de Chile.

REFERENCES

AQChN (Air Quality Chilean Normative) 1998. Decreto Supremo N°59, Ministry Secretaria General de la Presidencia, May 25.

Casmassi, J.C. 1999. Improvement of the forecast of air quality and of the knowledge of the local meteorological conditions in the Metropolitan Region, CONAMA, Technical Report.

Database 2010. Centro Nacional del Medio Ambiente, Santiago, Chile.

Dockery, D., Pope, C., Xu, X., Spengler, J., Ware, J., Fay, M., Ferris, B., and Speizer, F. 1993. An association between air pollution and mortality in six U.S. cities. New England Journal of Medicine, 329: 1753-1759.

Kampa, M. and Castanas, E. 2008. Human health effects of air pollution. Environmental Pollution, 151: 362-367.

Leiva, M.A., Sei, K., Soda, S., Yanai, J. and Chen, A. 2004. APRU Special Paper. Association of Pacific Rim Universities, Singapore, pp. 6-24.

Molina, M.J. and Molina, L.T. 2004. Megacities and atmospheric pollution. Journal of the Air & Waste Management Association, 54(6): 644-680.

Morales R.G.E. (Ed.) 2006. Atmospheric Urban Pollution. Critical Episodes at Santiago de Chile city. Editorial Universitaria, Santiago, Chile.

Rutllant, J.A. 1994. On the generation of coastal lows in Central Chile, International Centre for Theoretical Physics, Internal Report IC/94/167. Miramare-Trieste, Italy, 20 pp.

Rutllant, J.A. and Garreaud, R.D. 1995. Meteorological air pollution potential for Santiago, Chile: Towards an objective episode forecasting. Environmental Monitoring and Assessment, 34: 223-244.

Sandoval, H., Prendez, M.B. and Ulriksen, P. 1993. Atmospheric Pollution in Santiago. Current State and Results. Editorial Universitaria, Santiago, Chile.

Seguel, R., Morales, R.G.E. and Leiva, M.A. 2009. Estimations of primary and secondary organic carbon formation in PM2.5 aerosols of Santiago city, Chile. Atmospheric Environment, 43: 2125-2131.

Toro Richard 2010. Ph.D. Thesis, University of Chile, Santiago, Chile.