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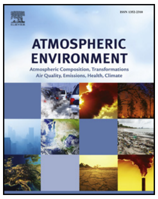

Impact of residential combustion and transport emissions on air pollution in Santiago during winter

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ABSTRACT

Santiago (33.5°S, 70.5°W), the capital of Chile, is frequently affected by extreme air pollution events during wintertime deteriorating air quality (AQ) and thus affecting the health of its population. Intense residential heating and on-road transport emissions combined with poor circulation and vertical mixing are the main factors responsible for these events. A modelling system composed of a chemistry-transport model (CHIMERE) and a meteorological model (WRF) was implemented to assess the AQ impacts of residential and transportation sources in the Santiago basin. A two-week period of July 2015 with various days with poor AQ was simulated focusing on the impact on AQ with respect to fully inhalable particles ($PM_{2.5}$) and nitrogen oxides (NO_X). Three emission scenarios, within the range of targeted reductions of the decontamination plan of Santiago, were tested; namely 50% reduction of residential emission, 50% reduction of transport emissions and the combination of both. An additional scenario decreasing transport emissions in 10% was carried out to examine whether a linear dependence of surface concentrations on changes in emissions exists.

The system was validated against surface and vertically resolved meteorological measurements. The model reproduces the daily surface concentration variability from the AQ monitoring network of Santiago. However, the model not fully captures the emissions variations inferred from the observations which may be due to missing sources such as resuspension of dust.

Results show that, during the period studied, although both residential and transportation sources contribute to observed AQ levels in Santiago, reducing transport emissions is more effective in terms of reducing the number of days with pollution events than decreasing residential combustion. This difference in impact is largely due to the spatial distribution of the emission sources. While most of the residential combustion is emitted in the outskirts of the city, most of the transport emissions occur within the city, where most of the stations from AQ monitoring network of Santiago are located. As can be expected, the largest improvement of AQ in Santiago is achieved by the combined reduction of emissions in both sectors. Sensitivity analysis with 10% reduction in transport emissions reveals a linear behavior between emissions and concentrations for NO_X and approximate linear behavior for $PM_{2.5}$. The absence of secondary aerosols formation and dust resuspension in the current simulation could explain this deviation from linearity for fine particles. Nevertheless, it suggests that the results can be used for mitigation policies with emissions reductions below the 50% used in this study.

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1. Introduction

During fall and winter period, extreme events of air pollution frequently affect the city of Santiago, capital of Chile (33.5°S, 70.5°W, 600 m a.s.l.), with strong impact on public health (Franck et al., 2014; Mullins and Bharadwaj, 2015). Although the number of these extreme events and average concentration levels decreased over the last decades (Barraza et al., 2017; Saide et al., 2016; Gallardo et al., 2018), such events still occur and they are a matter of public concern. These events consist of high levels of particulate matter (PM_{10} and $PM_{2.5}$) reaching hourly concentrations of 400–500 $\mu g/m^3$ of PM_{10} and 200–300 $\mu g/m^3$ of $PM_{2.5}$.

The composition of particulate matter in Santiago has been analyzed by Carbone et al. (2013) showing the predominance of organics (59%), while nitrate (14%) and ammonium (12%) dominate the non-organic compounds. Barraza et al. (2017) have quantified the contribution of emission sectors through a source attribution technique suggesting that in 2014, on an annual base, particle composition can be traced back to motor vehicles (37%), industrial sources (19%), copper smelters (14%), wood burning (12%), coastal sources (10%), and urban dust (3%). During the winter period, $PM_{2.5}$ contribution from residential combustion increases up to an average of 30% of the total amount of $PM_{2.5}$.

A large contribution to PM emissions is represented by residential heating and road transportation, estimated to emit respectively up to 1800 and 2700 tons/year of $PM_{2.5}$ in the year 2012 (USACH, 2014). These emissions are not evenly distributed throughout the year, especially the residential combustion emissions occur mostly during the winter season from May to September (Mena-Carrasco et al., 2012).

Air pollution in Santiago is strongly influenced by the complex topography surrounding it. The southern Andes (4500 m a.s.l.) in the east, the coastal range (1500 m a.s.l.) in the west and transversal mountain chains in the north and in the south surround the basin contributing to the occurrence of poor ventilation conditions. These topographic conditions are further strengthened by the influence of the Pacific subtropical high pressure system leading to poor ventilation and limited vertical mixing (Muñoz and Alcafuz, 2012). Moreover, thermal inversions are often intensified by recurrent sub-synoptic weather patterns known as coastal lows and described by Rutllant and Garreaud (1995) and Garreaud et al. (2002). These conditions prevent the dispersion of pollutants (Garreaud and Rutllant, 2003) leading to accumulation of gases (CO, NO_X and VOCs) and aerosols (PM_{10} and $PM_{2.5}$) (Villalobos et al., 2015; Gramsch et al., 2006, 2014; Gallardo et al., 2002; Saide et al., 2011).

Since 2000, several numerical models have been applied with different approaches in Chile to study air quality. The first studies were focused on the relationship between emissions of CO, NO_X, SO_X and PM_{10} and their impact on Santiago's air quality (Jorquera, 2002a; b; Gallardo et al., 2002; Olivares et al., 2002; Schmitz, 2005). More recent works have focused on forecasting $PM_{2.5}$ concentrations in Santiago using CO as a tracer (Saide et al., 2011, 2016) while others have made predictions of hourly average concentrations of $PM_{2.5}$ in downtown Santiago based on statistical approaches (Perez et al., 2000; Pérez and Gramsch, 2016).

A natural next step is to use numerical models simulating simultaneously both particulate matter and gaseous pollutants in order to have a complete description of their formation and dispersion patterns in the Santiago basin.

The aim of this work is to set-up a chemistry and transport model (CTM) for the Santiago region and to assess the impact of potential reduction of residential combustion and/or transport emissions of $PM_{2.5}$ and NO_X on Santiago's air quality. These emissions scenarios, explained in Section 2.4, are within the range of the emissions reduction targeted in the current decontamination plan for Santiago from the Ministry of the Environment (MMAplan, 2014). In particular, the plan provides for significant emission reductions in the transport and residential sector. For the former, this will be achieved by progressive passage of public and private vehicles to more modern “EURO” engine versions whereas for the latter, a ban on the use of wood for combustion in the entire metropolitan region and the progressive transition to other types of fuels (e.g. electricity, natural gas) is envisaged as well as the replacement of current stoves by more efficient and cleaner ones.

The paper is organized as follows: Section 2 describes the main features of the modelling system, the different observations used to evaluate its performance and gives a short description of the air quality conditions observed during the simulated period. In Section 3 we present the validation of the modelling system, the dispersions patterns within the Santiago basin and the assessment of the impact of reducing residential combustion and/or road transport emissions. Finally, the main conclusions are presented in Section 4.

2. Methodology

In this work we use the Weather Research and Forecasts Model (WRF), version 3.7.1 (Skamarock et al., 2008), with the CTM CHIMERE, version 2014b (Menut et al., 2013), to simulate the winter period from 15th to 28th of July 2015. The period has been chosen on one hand because of the high concentrations of $PM_{2.5}$ observed during these days and, on the other hand, because of vertical atmospheric measurements available for those days due to a campaign conducted in Santiago. A list of the configurations adopted for each model is provided in Table 1. The evaluation of the modeling system is done by assessing first the meteorological model (Section 2.2) and then the CTM (Section 2.3). Both models are evaluated against available surface and profile observations. Model performance is assessed through standard statistics: mean bias, root mean square error (RMSE) and Pearson correlation coefficient (R). Normalized versions of the mean bias and RMSE (MNB and NRMSE, respectively) are used to evaluate WRF's performance to reproduce surface and profile observations (Monteiro et al., 2007; Vautard et al., 2007; Borrego et al., 2008). Finally, different emissions scenarios for Santiago are tested with the modelling system (Section 2.4).

2.1. Observations

In order to assess the models ability to simulate the dispersion of pollutants in Santiago, we used observations from two different networks (Fig. 1).

Surface meteorological parameters (temperature, relative humidity at 2 m, wind direction and speed at 2 m and 10 m) from the Chilean weather service (DMC, from Spanish: Direccion Meteorolgica de Chile - www.meteochile.gob.cl/) are used. This network consists of eight

Table 1
Main configuration options applied in the meteorological model (WRF) and chemical transport model (CHIMERE) from the modelling system used in this work.

Process type	Parameters	References
WRF		
Initial and Boundaries Conditions	GFS final analysis - FNLs	Wu et al. (2002)
PBL Parametrization	MYNN2	Nenes et al. (1998)
Land Use	GEPLU	Zhao et al. (2016)
Radiation Scheme	CAM	Collins et al. (2004)
CHIMERE		
Chemistry	SAPRC07-A	Carter (2010)
Photolysis Rate Constants	TUV	Madronich et al. (1998)
Gas/aerosol partition	ISORROPIA	Nenes et al. (1998)
Horizontal and Vertical Transport	Van Leer	van Leer (1979)
Initial and Boundaries Conditions	LMDz-INCA	Hauglustaine et al. (2014)