



# Meteorological, PM<sub>2.5</sub> and PM<sub>10</sub> factors on SARS-COV-2 transmission: The case of southern regions in Chile <sup>☆</sup>

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## ABSTRACT

There are several determinants of a population's health, including meteorological factors and air pollution. For example, it is well known that low temperatures and air pollution increase mortality rates in infant and elderly populations. With the emergence of SARS-COV-2, it is important to understand what factors contribute to its mitigation and control. There is some research in this area which shows scientific evidence on the virus's behavior in the face of these variables. This research aims to quantify the impact of climatic factors and environmental pollution on SARS-COV-2 specifically the effect on the number of new infections in different areas of Chile. At the local level, historical information available from the Department of Statistics and Health Information, the Chilean National Air Quality Information System, the Chilean Meteorological Directorate, and other databases will allow the generation of panel data suitable for the analysis. The results show the significant effect of pollution and climate variables measured in lags and will allow us to explain the behavior of the pandemic by identifying the relevant factors affecting health, using heteroskedastic models, which in turn will serve as a contribution to the generation of more effective and timely public policies for the control of the pandemic.

## 1. Introduction

Since the 2009 influenza pandemic, countries have improved and strengthened their surveillance and monitoring systems to contribute to timely health decision-making (Sosa et al., 2017). In this regard, several endogenous and exogenous conditions affect the population's health. In particular, there is evidence that extreme temperatures are important health risks (Ren et al., 2006; Näyhä, 2005; Basu and Samet, 2002; Martens, 1998; Tanis and Karakaya, 2021), the most studied being increased mortality due to low temperatures. On the other hand, air pollution is associated with a number of harmful effects on human health (Bell et al., 2004; Samet et al., 2000; Zhang et al., 2020; André, 2020; Zhu et al., 2020).

Given the emergence of SARS-COV-2, it is relevant to understand what factors contribute to its mitigation and control. The main route of transmission of the virus was person to person through respiratory droplets, contaminated hands or surfaces (Noorimotlagh et al., 2021a).

To date, there is no scientific evidence in Chile on the behavior of this virus in the presence of environmental contamination. Worldwide, some studies in this area Zhao et al. (2021); Zhang et al. (2020); Xu et al. (2020); Coker et al. (2020); Gupta et al. (2021); Karan et al. (2020); Lolli et al. (2020) show scientific evidence on SARS-COV-2's behavior in the presence of these variables. Studies have shown that increased pollutant concentrations are associated with a higher daily incidence of SARS-COV-2 and an increased mortality rate (Contini and Costabile, 2020; Domingo and Rovira, 2020; Maleki et al., 2021; Noorimotlagh et al., 2021b).

In recent years, air pollution in some areas of Chile has reached high levels, and several cities in the country have been declared saturated. In southern Chile, the main heating source used in more than 80% of homes is firewood, although, at the national level, only 33.2% of homes use it. Fifty-two percent of Chileans consider the combustion of firewood to be the worst pollutant according to the Third National

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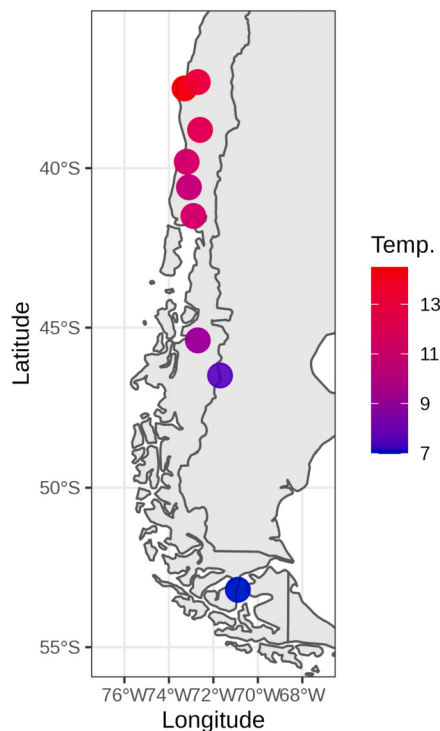


Fig. 1. Average Temperature in 2020.

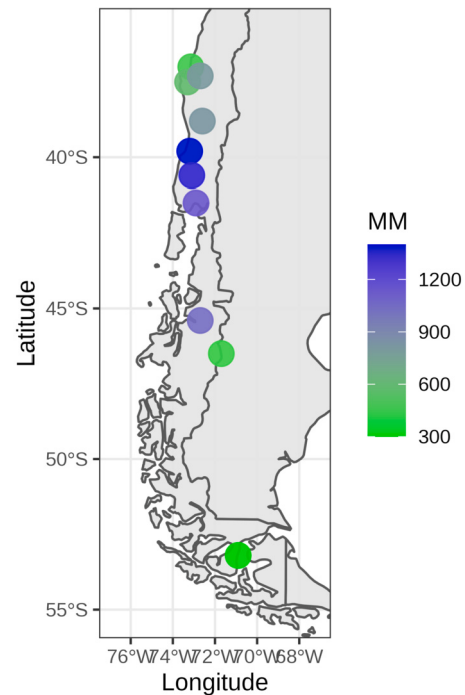


Fig. 2. Rainfall (mm) during 2020.

Environmental Survey (Anon, 2018), and it is the main source of pollution due to the emission of particulate matter (PM) it generates.

In this context, the State of Chile has implemented a public program to mitigate atmospheric pollution called Atmospheric Decontamination Plans (Anon, 2022). These are environmental management instruments that, through the definition and implementation of specific measures and actions, seek to reduce the levels of atmospheric pollution to protect the health of the population.

On the other hand, meteorological factors also affect people's health. The effects of climatic variables on health are an area of knowledge that has been widely discussed (Ahmadi et al., 2020; Auler et al., 2020; Bashir et al., 2020), mainly the increase in mortality caused by changes in temperature due to circulatory and respiratory diseases. Different studies Díez (1996); Bertollini et al. (1996) show that extreme temperatures are related to increased mortality rates.

In the Chilean south there is a heterogeneity of climate ranges from temperate climates to polar. Precipitations can reach 5,000 mm per year, as a consequence of low pressures due to low pressures coming from the south pole (Biblioteca del Congreso Nacional de Chile, 2022). The average temperature in 2020 presented normal conditions in the southern part of the country, in cities such as Concepción, Puerto Montt and Punta Arenas the annual average temperature was 13.4 °C, 10.7 °C, and 7 °C, respectively (Fig. 1). On the other hand, the total rainfall was characterized by deficits in most of the area where, in cities such as Concepción, Puerto Montt and Punta Arenas the total rainfall amounts reached only 808.8, 1325.0 and 299.6 millimeters per year respectively (Fig. 2) (Dirección Meteorológica de Chile, 2022).

Investigating the relationship between meteorological factors and environmental pollution with SARS-COV-2 is of utmost importance, given the lack of evidence in this regard. At the local level, it allows us to identify both the effects and the dynamics of the pandemic in highly polluted areas. It will also allow forecasts to be made for temperature increases, decreases, or climate change scenarios.

Other factors that can affect virus transmission include culture, family and housing structure, and other variables such as vaccination (Ganslmeier et al., 2021; Poirier et al., 2020; Sahoo et al., 2020), GDP per capita, healthcare expenditures, strategies of pandemic manage-

ment Coccia (2021a) that is, the effect of coronavirus on people's health depends on many economic, social and environmental variables (Coccia, 2021b, 2020a, 2021c; Sabat et al., 2020; Qiu et al., 2020).

This research aims to quantify the impact of meteorological factors and environmental pollution on the respiratory disease SARS-COV-2 using a heteroskedastic linear regression model. Specifically, the effect on the number of new infections in the different areas of Chile studied, and the pandemic's behavior concerning meteorological and environmental conditions. Furthermore, this study aims to help provide decision-makers with tools to improve their ability to react.

## 2. Materials and methods

This study uses different data sources. First, the Air Quality Measurements data panel obtained from the National Air Quality Information System website National air quality information system (2022) from March 2020 to October 2021 when most of the population had already been inoculated. In particular, information on daily concentrations ( $\mu\text{g}/\text{m}^3$ ) of PM10 and PM2.5 from different monitoring stations located throughout the country is used. The study is carried out in six areas in southern Chile. In total, a network of approximately 60 monitoring stations is used throughout the country, which are described in Table 1.

Secondly, the panel of meteorological data on temperature (degrees °C) and rainfall (mm), obtained from the same monitoring stations or, if the information is not available, from the Chilean Meteorological Directorate are used. The geographical location is shown in Figs. 1, 2 and 3.

The number of medical visits by cause and week is obtained from the Department of Health Statistics and Information (Department of health statistics and information, 2022). The data contained weekly statistical information for each of the public health centers. Finally, the health centers used here are Hospitals, Emergency Primary Care Service (SAPU) or High Resolution Primary Emergency Care Service (SAR).

### Statistical model

In this section we show the statistical model in its functional form, which we use to study the relationship between pollutants, meteorological variables and SARS-COV-2 incidence:

**Table 1**  
Health center locations by municipality and region.

| Region                                         | Municipality    | Health Center                                                                                                                                                                   |
|------------------------------------------------|-----------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Del Bío-bío</b>                             | Coronel         | Hospital San José (Coronel), SAPU Lagunillas, Sapu Yobilo                                                                                                                       |
|                                                | Curanilahue     | Hospital Provincial Dr. Rafael Avaria (Curanilahue), SAPU Eleuterio Ramírez                                                                                                     |
|                                                | Los Ángeles     | Complejo Asistencial Dr. Víctor Ríos Ruiz (Los Angeles), SAPU Paillihue, SAR Norte, SAR Entre Ríos, SAPU Dos de Septiembre, SAPU Nororiente, SAPU Nuevo Horizonte, SUR Santa Fe |
|                                                | Laja            | Hospital de Laja                                                                                                                                                                |
|                                                | Nacimiento      | Hospital de Nacimiento                                                                                                                                                          |
| <b>De La Araucanía</b>                         | Temuco          | SAPU Santa Rosa, SAR Miraflores, SAPU Amanecer, SAPU Pueblo Nuevo, SAPU Villa Alegre, SAR Labranza, SAR Pedro de Valdivia, Hospital Dr. Hernán Henríquez Aravena (Temuco)       |
|                                                | Padre Las Casas | SAPU Padre Las Casas, SAPU Pulmahue, Hospital Makewe, SAR Conun Huenú, Complejo Asistencial Padre Las Casas                                                                     |
| <b>De Los Ríos</b>                             | Valdivia        | Hospital Clínico Regional (Valdivia), SAPU Las Animas, SAPU Gil de Castro, SAPU Angachilla, SAR Barrios Bajos, SAPU Niebla                                                      |
|                                                | La Unión        | Hospital Juan Morey (La Unión), SAR La Unión                                                                                                                                    |
| <b>De Los Lagos</b>                            | Puerto Montt    | SAPU Angelmó, SAPU Antonio Varas, SAPU Padre Hurtado, SAR Alerce, SAPU Carmela Carvajal, Hospital de Puerto Montt                                                               |
|                                                | Osorno          | Hospital Base de Osorno, SAPU Dr. Pedro Jáuregui, SAPU Rahue Alto, SAPU Dr. Marcelo Lopetegui Adams                                                                             |
| <b>De Aisén del Gral. C. Ibáñez del Campo</b>  | Coihaique       | Hospital regional Coihaique, SAPU Dr. Alejandro Gutiérrez                                                                                                                       |
|                                                | Aisén           | Hospital de Puerto Aisén                                                                                                                                                        |
|                                                | Cisnes          | Hospital Dr. Jorge Ibar (Cisnes)                                                                                                                                                |
|                                                | Cochrane        | Hospital Lord Cochrane                                                                                                                                                          |
|                                                | Chile Chico     | Hospital Dr. Leopoldo Ortega R. (Chile Chico)                                                                                                                                   |
| <b>De Magallanes y de La Antártica Chilena</b> | Punta Arenas    | Hospital D. Lautaro Navarro Avaria (Punta Arenas), SAPU Dr. Mateo Bencur, SAPU Dr. Juan Damianovic, SAPU 18 de Septiembre                                                       |
|                                                | Cabo de Hornos  | Hospital Comunitario Cristina Calderón de Puerto Williams                                                                                                                       |
|                                                | Porvenir        | Hospital Dr. Marco Antonio Chamorro (Porvenir)                                                                                                                                  |

$$y_{it} = f(MP10_{it}, L1(MP10_{it}), L2(MP10_{it}), MP2.5_{it}, L1(MP2.5_{it}),$$

$$L2(MP2.5_{it}), T_{it}, L1(T_{it}), L2(T_{it}), Pre_{it}, L1(Pre_{it}), L2(Pre_{it})), \quad (1)$$

where  $y_{it}$  corresponds to the number of new confirmed SARS-COV-2 cases, at health center  $i$  at week  $t$ ;  $MP10_{it}$  corresponds to the daily concentrations ( $\mu\text{g}/\text{m}^3$ ) of PM10, at health center  $i$ , during week  $t$ ;  $MP2.5_{it}$  corresponds to the daily concentrations ( $\mu\text{g}/\text{m}^3$ ) of PM2.5, at health center  $i$  at week  $t$ ;  $T_{it}$  corresponds to the average ambient temperature ( $^{\circ}\text{C}$ ) at health facility  $i$  at week  $t$ ;  $Pre_{it}$  corresponds to the precipitation at health center  $i$  at week  $t$ . All the variables described are sampled in one week. Finally, L1 and L2 correspond to variables with a lag of one week and two weeks respectively.

From Equation (1), the following statistical models are established as a response of the dependent variable  $y_{it}$  in terms of the explanatory variables. The statistical model of Equation (2) corresponds to a fixed-effects model with the assumption of heteroscedasticity, where we can identify the specific factor of the week ( $\tau_i$ ) and of the corresponding health center for which the information for the modeling is obtained ( $v_i$ ). The model is controlled by an appropriate characterization of the model variance expressed in the Equation (3), using Harvey's two-step generalized least squares method (Harvey, 1976; Greene, 2018; Altonji and Segal, 1996; Clark, 1996). The two-step generalized least squares method is more efficient when the correct specification of the mean and variance is not known, as in this case.

$$y_{it} = \beta_0 + \beta_1 MP10_{it} + \beta_2 L1(MP10_{it}) + \beta_3 L2(MP10_{it}) + \beta_4 MP2.5_{it} + \beta_5 L1(MP2.5_{it}) + \beta_6 L2(MP2.5_{it}) + \beta_7 T_{it} + \beta_8 L1(T_{it}) + \beta_9 L2(T_{it}) +$$

$$\beta_{10} Pre_{it} + \beta_{11} L1(Pre_{it}) + \beta_{12} L2(Pre_{it}) + v_i + \tau_i + \varepsilon_{it}, \quad (2)$$

$$\sigma_{it}^2 = \exp(\alpha_0 + \alpha_1 MP10_{it} + \alpha_2 L1(MP10_{it}) + \alpha_3 L2(MP10_{it}) + \alpha_4 MP2.5_{it} + \alpha_5 L1(MP2.5_{it}) + \alpha_6 L2(MP2.5_{it}) + \alpha_7 T_{it} + \alpha_8 L1(T_{it}) + \alpha_9 L2(T_{it}) + \alpha_{10} Pre_{it} + \alpha_{11} L1(Pre_{it}) + \alpha_{12} L2(Pre_{it}) + \delta_i + \rho_t), \quad (3)$$

$$\varepsilon_{it} \sim N(0, \sigma_{it}^2); \quad Cov(\varepsilon_{it}, \varepsilon_{js}) = 0; \quad i \neq j; \quad t \neq s. \quad (4)$$

A model that controls for heteroscedasticity has been used for this research, because a high variability of the response of geographical areas is to be expected due to region-specific socio-economic and political differences. In addition, the non-linearity of the environmental pollution variables that may be involved in the behavior of the variance is not clear. This type of model allows us to control for heteroscedasticity effects and provides a flexible tool for the proper modeling of the data.

### 3. Results

The first statistical model is called Model 1 and considers the following explanatory variables: (i) MP2.5; (ii) L1(MP2.5); (iii) L2(MP2.5); (iv) MP10; (v) L1(MP10); (vi) L2(MP10). The second, is called Model 2 and considers in addition to the explanatory variables of Model 1 the following variables: (vii) T; (viii) L1(T); (ix) L2(T); (x) Pre; (xi) L1(Pre); (xii) L2(Pre). For both models, the health centers and the respective week are considered as fixed effects. These two models are presented as alternatives, where the second model considers meteorological variables as a control, allowing comparison with other models presented in

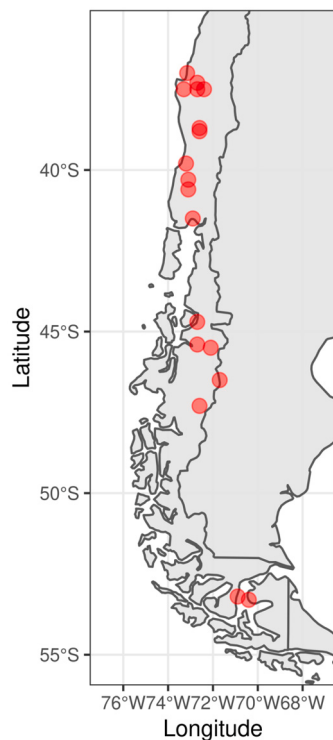


Fig. 3. Weather and pollutant monitoring stations.

**Table 2**  
Parameter estimate and significance level.

| Variable           | OLS Estimator      | Lineal Regression |               |
|--------------------|--------------------|-------------------|---------------|
|                    |                    | Model 1           | Model 2       |
| MP2.5              | $\hat{\beta}_1$    | 0.002796 ns       | 0.0030147 ns  |
| L1(MP2.5)          | $\hat{\beta}_2$    | -0.000096 ns      | -0.0005504 ns |
| L2(MP2.5)          | $\hat{\beta}_3$    | -0.000715 ns      | -0.0009616 ns |
| MP10               | $\hat{\beta}_4$    | -0.001568 ns      | -0.0017679 ns |
| L1(MP10)           | $\hat{\beta}_5$    | 0.0003358 ns      | 0.0002483 ns  |
| L2(MP10)           | $\hat{\beta}_6$    | 0.001201 ns       | 0.0012701 ns  |
| T                  | $\hat{\beta}_7$    |                   | -0.0034373 ns |
| L1(T)              | $\hat{\beta}_8$    |                   | -0.0321138 ns |
| L2(T)              | $\hat{\beta}_9$    |                   | -0.0298265 ns |
| Pre                | $\hat{\beta}_{10}$ |                   | -2.13e-43 ns  |
| L1(Pre)            | $\hat{\beta}_{11}$ |                   | 3.02e-44 ns   |
| L2(Pre)            | $\hat{\beta}_{12}$ |                   | -1.14e-43 ns  |
| Constant           |                    | 4.39259***        | 5.80982***    |
| N                  |                    | 2343              | 2008          |
| Week               |                    | Fixed             | Fixed         |
| Center             |                    | Fixed             | Fixed         |
| R <sup>2</sup>     |                    | 0.5913            | 0.5720        |
| F-statistic        |                    | 25.88             | 21.01         |
| Breusch-Pagan test |                    |                   |               |
| $\chi^2(1)$        |                    | 2282.29           | 2062.60       |
| Prob> $\chi^2$     |                    | < 0.001           | < 0.001       |

\*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ , ns = non-significant.

recent literature. The fundamental reason for exposing these two models is that meteorological information is not available for all localities that have health centers, so a robustness analysis is required to validate the effects of the environmental pollution variables.

Table 2 shows the ordinary linear regression (OLS) analysis of Models 1 and 2. For both models, it is observed that the variables of interest are not significant, although the coefficient of determination ( $R^2$ ) shows

values 0.5913 for Model 1 and 0.572 for Model 2, which represents the proportion of the variance that we are able to explain by OLS models.

Observing a relatively high  $R^2$ , a high F-statistic, but no significance of any of the variables for the two models, gives us signs that we have some problems with the modeling of the phenomenon. We analyze the heteroscedasticity effect of the study variables. For this, the Breusch-Pagan test which has a  $\chi^2$  distribution, is applied to evaluate the heteroscedasticity effect in the linear regression model. Rejection of the null hypothesis implies that the homoscedasticity hypothesis is rejected and therefore a model that controls for variance is preferred. It can be observed that the null hypothesis of non-heteroscedasticity for both models is rejected. Therefore, the model must consider the effect that the variables may have on the variance of the linear model. Table 3 shows linear regression considering the effects of heteroscedasticity on Models 1 and 2, respectively. The same variables in Models 1 and 2 without heteroscedasticity are considered.

The likelihood ratio test for  $\log(\sigma^2) = 0$  presented in Table 3 which is distributed  $\chi^2$ , indicates that the null hypothesis that the variance is constant is rejected, therefore, the model that considers heteroscedasticity is appropriate for both models.

Finally, based on the Breusch-Pagan test and the constant variance test presented in Table 2 and 3 respectively, we conclude that it is better to consider the model that considers heteroscedasticity than an ordinary linear model (OLS).

The analysis of the model considering heteroscedasticity shows that the pollution variables MP2.5, L2(MP2.5), MP10, and L2(MP10) are significant for both models.

For the case of Model 2, the variables L1(T) and L2(T) are also significant. The variables MP2.5, L1(MP2.5), and MP10 are significant in the variance modeling for Model 1, while for Model 2, the variables MP10, and L1(T) are significant.

#### 4. Discussion

In the present study, the potential effects of meteorological variables and air pollution on the incidence of SARS-COV-2 are preliminary evaluated, since the arrival of the virus in Chile, week by week, from march 2020 to October 2021. Chile is located in the southern hemisphere, and presents relevant meteorological differences when compared to Europe and Asia.

In general, based on data from six regions in southern Chile, our results show that new cases of SARS-COV-2 have a strong association with temperature and air pollution. In addition, the results show the lagged effects of temperature and pollution variables affecting the temporal dynamics of SARS-COV-2 cases.

In particular, the results of the model considering heteroscedasticity show that low temperatures affect the incidence of new infections in the subsequent weeks, which may be due to the incubation period of the virus. Precipitation is not shown to be related to the disease. Other studies have similar conclusions about the seasonality of coronavirus infections, showing a negative association between temperature and virus incidence, that is, low temperatures are associated with increased risks of SARS-COV-2 incidence (Ganslmeier et al., 2021; Nottmeyer et al., 2023).

In relation to air pollution, our results show a strong association with the incidence of SARS-COV-2. Specifically, coarse particle (PM10) affects the number of diagnoses in the subsequent week, while fine particulate matter (PM2.5) affects the number of diagnoses in the same week. The latter may be because the smaller size of this pollutant allows it to penetrate directly into the airways reaching the lungs and alveoli (Gil, 2007). Particulate matter is a mixture of solid and liquid particles found in the air, some of these particles are large and dark enough to be seen with the naked eye (PM10 whose diameter is less than 10 micrometers) while others can only be detected with a microscope (PM2.5 whose diameter is less than 2.5 micrometers) (U.E.P. Agency, 2022). Due to their small size they can be inhaled and cause

**Table 3**

Parameter estimate and significance level of the regression considering heteroscedasticity.

| Variable                                        | Estimators                     | Lineal Regression |              | log( $\sigma^2$ ) |              |
|-------------------------------------------------|--------------------------------|-------------------|--------------|-------------------|--------------|
|                                                 |                                | Model 1           | Model 2      | Model 1           | Model 2      |
| MP2.5                                           | $\beta_1$ and $\alpha_1$       | 0.00191**         | 0.00238**    | 0.00996*          | 0.00837 ns   |
| L1(MP2.5)                                       | $\beta_2$ and $\alpha_2$       | 0.000269 ns       | −0.000363 ns | −0.0110*          | −0.00716 ns  |
| L2(MP2.5)                                       | $\beta_3$ and $\alpha_3$       | −0.00192**        | −0.00188*    | −0.00117 ns       | −0.000835 ns |
| MP10                                            | $\beta_4$ and $\alpha_4$       | −0.00129*         | −0.00176**   | −0.00878*         | −0.0102**    |
| L1(MP10)                                        | $\beta_5$ and $\alpha_5$       | 0.000467 ns       | 0.00104 ns   | 0.00527 ns        | 0.00396 ns   |
| L2(MP10)                                        | $\beta_6$ and $\alpha_6$       | 0.00205**         | 0.00174**    | −0.00114 ns       | 0.00241 ns   |
| T                                               | $\beta_7$ and $\alpha_7$       |                   | 0.00308 ns   |                   | −0.0358 ns   |
| L1(T)                                           | $\beta_8$ and $\alpha_8$       |                   | −0.0201**    |                   | −0.0124 ns   |
| L2(T)                                           | $\beta_9$ and $\alpha_9$       |                   | −0.0271***   |                   | −0.0765*     |
| Pre                                             | $\beta_{10}$ and $\alpha_{10}$ |                   | −1.06e-43 ns |                   | 2.12e-43 ns  |
| L1(Pre)                                         | $\beta_{11}$ and $\alpha_{11}$ |                   | −8.76e-44 ns |                   | −3.08e-43 ns |
| L2(Pre)                                         | $\beta_{12}$ and $\alpha_{12}$ |                   | −1.05e-43 ns |                   | 4.08e-43 ns  |
| Constant                                        |                                | 4.673***          | 5.700***     | 3.571***          | 6.250***     |
| N                                               |                                | 2343              | 2008         | –                 | –            |
| Week                                            |                                | Fixed             | Fixed        | Fixed             | Fixed        |
| Center                                          |                                | Fixed             | Fixed        | Fixed             | Fixed        |
| Likelihood Ratio Test for log( $\sigma^2$ ) = 0 |                                |                   |              |                   |              |
| $\chi^2$                                        |                                | 1165.12           | 991.62       | –                 | –            |
| Prob> $\chi^2$                                  |                                | < 0.001           | < 0.001      | –                 | –            |

\*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ , ns = non-significant.

cardiovascular and respiratory diseases throughout the community that is exposed to the emissions. Smaller particulate matter can enter the respiratory tract and reach the lungs, alveoli, and can sometimes reach the bloodstream (Gil, 2007). Previous studies have found similar results, including the impacts of air pollution and weather conditions on the incidence of COVID-19 (Jiang et al., 2020; Akan, 2022), and the relationship between high air pollution and low wind speeds that can favor the spread of COVID-19 and other infectious diseases (Coccia, 2020b, 2021d).

Different studies on the effect of lockdown revealed a reduction in the concentration of PM2.5, PM10 and other gaseous pollutants Li et al. (2020); Collivignarelli et al. (2020); Nakada and Urban (2020); Chauhan and Singh (2020); Mandal and Pal (2020); Sharma et al. (2020); Srivastava (2021) while, in the case of ozone, its concentration increased, thus having a curative effect on the ozone layer (Li et al., 2020; Collivignarelli et al., 2020; Nakada and Urban, 2020; Sharma et al., 2020; Srivastava, 2021). The reduction in the air pollution due to lockdown shows a decrease in mortality and morbidity, and with them a number of health and economic benefits associated with these measures (Cui et al., 2020). These lessons allow us to face the great challenge of advancing in the reduction of atmospheric pollution through the use of technologies to increase remote working (Nakada and Urban, 2020), remote education, and other services.

These results show that permanent control and prevention of environmental pollution play a vital role in controlling the health crisis and minimizing the impact on people's health. Although the study was carried out in the southern part of the country, the relationship found between the incidence of SARS-COV-2 and air pollution is evident. Other important lessons learned during the pandemic include avoiding overburdening health services and reducing transmission (Canals, 2020).

## 5. Conclusion

This study brings novelty in the field of SARS-COV-2 viral disease environment for nine regions of southern Chile, a country located in the southern hemisphere. We have included lagged variables for both meteorological and pollution variables, and controls by statistical week, and health centers, which allows us to capture any variation that exists in time and space caused by possible differences in health policies specific to each geographical area.

The results obtained in this study are consistent with the findings of other investigators about the relationship between the incidence of

SARS-COV-2 with temperature and air pollution (PM10 and PM2.5). On the one hand, low temperatures are related to an increase in new cases in the following weeks.

Furthermore, air pollution is positively related to the incidence of the virus. Specifically, coarse particles affect the number of diagnoses in the following week, while fine particles affect the incidence in the same week.

Future studies are planned on mortality levels related to SARS-COV-2 and its relationship with climatic and pollution variables. These studies will also include new pollutants, other socioeconomic variables (population, distance between cities, income, among others) and the study area will extend to the entire country, where the climates and pollution factors vary greatly. Finally, it is interesting to study how vaccination has affected incidence and mortality levels related to the pandemic.

## CRediT authorship contribution statement

All authors contributed equally to the development of the research, both in data analysis and writing of the manuscript.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

Data will be made available on request.

The datasets used during this study are included in this published article.

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