Short-Term Effects of Saharan Dust Intrusions and Biomass combustion on Birth Outcomes in Spain

Moreira, Irina S.; Linares, Cristina; Follos, F.; Sanchez Martinez, Gerardo; Diaz, Julio

Published in:
Science of the Total Environment

Link to article, DOI:
[10.1016/j.scitotenv.2019.134755](https://doi.org/10.1016/j.scitotenv.2019.134755)

Publication date:
2020

Document Version
Peer reviewed version

[Link back to DTU Orbit](#)

Citation (APA):
Moreira, I. S., Linares, C., Follos, F., Sanchez Martinez, G., & Diaz, J. (2020). Short-Term Effects of Saharan Dust Intrusions and Biomass combustion on Birth Outcomes in Spain. *Science of the Total Environment*, 701, [134755]. <https://doi.org/10.1016/j.scitotenv.2019.134755>

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

1

2

3

4

5

6

7

8

9

10

11

12

Short-Term Effects of Saharan Dust Intrusions and Biomass combustion on Birth Outcomes in Spain

Moreira I¹, Linares C¹, Follos F², Sánchez-Martínez G³, Vellón JM², Díaz J¹

- (1) Escuela Nacional de Sanidad, Instituto de Salud Carlos III, Madrid, Spain**
- (2) Tdot Soluciones Sostenibles, S.L. Ferrol, A Coruña, Spain.**
- (3) The UNEP DTU Partnership, Copenhagen, Denmark.**

Abstract:

The objective of this study is to analyze the short-term effects of atmospheric pollutant concentrations (PM_{10} , NO_2 and O_3) and heat and cold waves on the number of pre-term births and cases of low birth weight related to Saharan dust advection and biomass combustion. The dependent variables used in this analysis were the total number of births, births with low weight ($>2.500g$) and pre-term births (<37 weeks), that occurred at the province level. Data provided by the NSI included: days with Saharan dust intrusion or biomass advection classified in terms of information provided by MITECO for each of the nine regions in Spain. A representative city was selected for each region in which the registered average daily concentrations of PM_{10} , NO_2 and O_3 ($\mu g/m^3$) were used. These were also provided by MITECO. The daily maximum and daily minimum temperature ($^{\circ}C$) used was those registered by the meteorological observatory station located in each province capital, provided by AEMET. Using Poisson log linear regression models, the associated relative risks (RR) were measured as well as the population attributable risk (PAR) corresponding to the variables that resulted statistically significant at $p<0.05$ for days with and without intrusion of natural particulate matter.

The results obtained show that the days with Saharan dust intrusion or advections due to biomass combustion- beyond the impact of PM_{10} , primary pollutants such as NO_2 (in Saharan intrusions), heat waves and O_3 - are associated with the number of births, low birth weight and pre-term birth. The RR and percent PAR of the pollutants and the heat waves are greater than those obtained for PM_{10} .

The results of this study indicate that days with natural particulate matter due to biomass combustion or advection of Saharan dust put pregnant women at risk.

1. Introduction

There are numerous studies that analyze the impact of the advection of particulate matter that comes from both biomass combustion – generally from forest fires (Linares et al., 2018) – and from the Sahara (Díaz et al., 2017). These types of particulates are especially important in urban areas, and they contribute to increases of four percent in the levels of particulate matter in Spain (Viana et al., 2014).

Most studies link the increase in concentrations of particulate matter that come from the Sahara to daily mortality (Pérez et al., 2012; Samoli et al., 2010) due to both natural causes (Jiménez et al., 2010) and specific causes, generally respiratory and circulatory (Pérez et al., 2012; Díaz et al., 2012). There are also studies, though fewer, that analyze how these Saharan origin advections can affect hospital admissions (Reyes et al., 2014), although some studies do not find conclusive results in terms of how Saharan dust can affect morbidity and mortality (Stafoggia et al., 2016). Although the principal causes of disease analyzed in these studies are cardio-respiratory (López-Villanueva et al., 2012), there are also publications that link Saharan dust intrusions to the increase in cases of infectious diseases such as meningitis (Tobías et al., 2011a). From a methodological point of view, there is quite a uniform approach. The methodology commonly used in this work is Poisson log linear regression models (Jiménez et al., 2010; Díaz et al., 2012; Stafoggia et al., 2016) or case crossover (Pérez et al., 2012; Tobías et al., 2011b) in which the independent variable is usually PM concentrations, and the models usually control for confounding variables such as temperature, humidity and other pollutants (Díaz et al., 2017). A few of these studies pay attention to atmospheric conditions that promote intrusion of natural origin materials and focus primarily on PM advection (Salvador et al., 2014).

Studies related to health incidence of particulate matter from biomass combustion in forest fires are less frequent than those related to Saharan dust (Finlay et al., 2012). They are

62 primarily focused on the impact of PM on hospital admissions due to respiratory problems
63 (Mirabelli et al., 2009) or the exacerbation of prior respiratory infections (Martin et al., 2013).
64 Though fewer, there are also studies that link exposure to forest fire dust with cardiovascular
65 disease (Weichenthal et al., 2017). In terms of mortality incidence, some studies do show the
66 existence of an association (Linares et al., 2018; Linares et al., 2015), especially for large fires
67 (Analitis et al., 2012). However, other studies show no type of relationship (Vedal and Dutton,
68 2006). The methodology proposed in these studies is similar to those already mentioned for
69 advection of PM of Saharan origin.

70 New studies establish that intrusions of Saharan dust provide not only particulate matter to
71 the atmosphere, but also, synoptic scale meteorological conditions that favor these advections
72 and modify the structure of the atmosphere, resulting in diminishing the height of the mixed
73 layer (Pandolfi et al., 2014). This modification of the atmosphere will have an impact not only
74 on the increase in particulate matter, but also on the difficulty of convective dispersion of all of
75 the atmospheric pollutants that will bring with them an increase in other pollutants such as
76 nitrogen oxides which are especially worrisome in the urban air (Salvador et al., 2019).
77 Therefore, an approach focused exclusively on the increase in PM as the cause of a greater
78 increase in morbidity and mortality should be expanded to include other pollutants such as
79 nitrogen oxides. In addition, the atmospheric conditions that give rise to the influx of Saharan
80 dust in Spain (Diaz et. al, 2017), along with forest fires (Linares et al., 2018) tend to be
81 associated with high temperatures and high insolation. Thus, other factors should be
82 considered that probably have an influence on population health, such as the case of
83 tropospheric ozone and heat waves (Jaffe et al., 2013).

84 Finally, it is notable that despite numerous studies related to the incidence of PM on
85 pregnancy (Dibben & Clemens, 2015; Pedersen et al., 2013, Stieb et al., 2012; Arroyo et
86 al., 2019 a,b) only a few studies have been carried out that analyze how natural origin PM

87 advections can influence the so-called adverse birth outcomes (Dadvand et al., 2011; Viel et
88 al., 2019).

89 Thus, as already mentioned, the objective of this study is to analyze how different
90 environmental factors such as concentrations of PM, NO₂ and ozone and the existence or not
91 of thermal extremes impact the number of births, pre-term births and births with low birth
92 weight that take place in Spain on days with Saharan dust intrusion and on days with intrusion
93 of particulate matter from biomass combustion.

94

95

2. Material and methods:

2.1 Determination of days with Saharan dust intrusion and particulate matter from biomass combustion

The classification of days with Saharan dust intrusion and with intrusion of particulate matter from biomass combustion was determined based on information provided by the Ministry for Ecological Transition (MITECO, 2019). In order to quantify the contributions of African dust to daily levels of PM₁₀ during African episodes, it is necessary to apply the methodology developed in tandem by the Ministry for Ecological Transition of Spain and the Portuguese Environmental Agency. "Procedure for the identification of natural episodes of PM₁₀ and PM_{2.5} and the demonstration of cause with respect to exceeding daily limit values of PM₁₀". This procedure can be found at (MITECO, 2013) and in the Directives of the European Commission (European Commission, 2011) .

According to this methodology, Spain is divided into nine areas labeled North, North-East, North-West, Center, South-East, South-West, East, Canary Islands, Balearic Islands, as shown in Figure 1. In order to identify the existence of a day with Saharan dust intrusion, an interpretation is carried out of retro-trajectories of air masses through synoptic maps and satellite images (maps of the aerosol index of Ozone Monitoring Instrument-OMI and NASA SeaWiFS images) and daily consultation of dust forecast models, namely: SKIRON-University of Athens, BSC-DREAM8b v2.0-Barcelona Supercomputing Centre and NAAPS-Naval Research Laboratory (NRL), Monterey, CA. This is one of the official measures recommended by the European Commission for the evaluation of the occurrence of African origin dust intrusions (Commission Staff Working Paper, 2011).

The determination of days with advection of particulate matter from biomass combustion in each of the nine regions of Spain mentioned before was carried out through the NAAPS (Navy Aerosol Analysis and Prediction System) Global Aerosol Model methodology. NAAPS is a global aerosol transport model maintained operationally by the U.S. Navy for predicting the distribution of tropospheric aerosols (<https://www.nrlmry.navy.mil/aerosol/>). The emissions, transport and sinks of smoke from biomass burning, among other aerosol sources, are simulated as forecast products, and are thereafter corrected from satellite aerosol optical depth measurements (Reid et al., 2009).

2.2 Dependent and independent variables

In each of the nine regions described above, a province was selected based on the existence and quality of air pollution, meteorological data and variables related to pregnancy. Thus, for the North Region the province was Vizcaya with capital Bilbao; for the North-East Region the province was Zaragoza with capital Zaragoza; for the North-West Region the province was A Coruña with the capital of the same name; in the Central Region the province was Madrid with capital Madrid; in the South-East Malaga Region; in the South-West Seville; in East Valencia; in Canary Islands the province was Las Palmas de Gran Canaria and in the Balearic Islands Region the province was Mallorca with capital Palma de Mallorca. The period used was from January 1, 2004 to December 31, 2009.

For each of these provinces the following data were used:

- As dependent variables:

Number of daily births in all of the municipalities of the province with over 10,000 inhabitants.

Number of daily births with low birth weight (LBW). Low birth weight is defined as those births with a weight of less than 2500g (ICD-10: P07.0-P07.1).

Number of daily pre-term births (PTB), that is, births occurring prior to 37 weeks of gestation (ICD-10: P07.2-P07.3).

The data for these three variables were obtained from the National Statistics Institute (INE, 2019).

- As independent variables:

Air pollution variables: Average daily concentrations of PM₁₀, NO₂ and O₃ (µg/m³) corresponding to the urban meteorological stations of the capital of each province already mentioned. The data were provided by the MITECO (MITECO, 2019).

Meteorological variables: Maximum daily temperatures (T_{max}) and minimum daily temperatures (T_{min}) registered in the reference observatory of the province located in the capital were used. Data were provided by the State Meteorological Agency (SMA)

Transformation of variables

Prior studies with the dependent variables described have shown that the functional relationship between the variables and the average daily concentrations of PM₁₀ and NO₂ are linear (Arroyo et al., 2019a, b). However, the functional relationship with O₃ is quadratic (Arroyo et al., 2019 a, b). That is, there is a value for the average daily concentration of ozone (O₃umbral) from which the impact on health should be considered (Díaz et al., 2018). This value varies from one city to another. Table 1 shows the O₃_{threshold} values for each of the provincial capitals considered in this study. Where there is no threshold, it is assumed that there is no impact of O₃ on the analyzed dependent variables.

A new variable O_{3h} was created based on the values of $O_{3threshold}$, defined in the following way (Díaz et al., 2018):

$$O_{3h} = 0 \quad \text{if } O_3 < O_{3threshold}$$

$$O_{3h} = O_3 - O_{3threshold} \quad \text{if } O_3 > O_{3threshold}$$

On the other hand, thermal extremes, heat waves and cold can also influence the gestation variables considered here (Arroyo et al., 2016; Arroyo et al., 2019 a, b). Synoptic scale meteorological situations that favor intrusions of natural origin particulate matter can also lead to the existence of extreme temperatures, therefore we considered the possible existence of heat and cold waves.

Heat waves are characterized by the existence of a maximum daily threshold temperature ($T_{threshold}$), for which the mortality due to heat increases in a statistically significant way (Díaz et al., 2015). The $T_{threshold}$ varies from one province to another. Table 1 shows the values of $T_{threshold}$ for each of the cities considered in this study. A new heat wave temperature T_{heat} was defined based on these values in the following way (Díaz et al., 2015):

$$T_{heat} = 0 \quad \text{si } T_{max} < T_{threshold}$$

$$T_{heat} = T_{max} - T_{threshold} \quad \text{Si } T_{max} > T_{threshold}$$

Similarly, in the case of the cold, there is a minimum daily temperature below which daily mortality increases in a statistically significant way. Table 1 shows these temperatures. Similarly, in the case of cold, a cold wave temperature is defined as follows (Carmona et al., 2016):

$$\begin{aligned}
 &T_{\text{cold}} = T_{\text{threshold}} - T_{\text{min}} && \text{si } T_{\text{min}} < T_{\text{threshold}} \\
 &T_{\text{cold}} = 0 && \text{si } T_{\text{min}} > T_{\text{threshold}}
 \end{aligned}$$

190

191 2.3 Analysis methodology:

192 We carried out a longitudinal ecological time series study to relate the dependent
 193 variables to the independent variables using log-linear models (GLM) with Poisson link. The
 194 analysis was performed both for days with advection of Saharan dust and for days without
 195 advection. In the same way, the analysis was repeated for days with and without intrusion of
 196 particulate material from biomass combustion.

197 In addition to the variables described above, this analysis included other variables to
 198 control for trend, seasonality, days of the week and the autoregressive character of the series.
 199 Seasons were taken into account using sine and cosine functions with annual, semestral,
 200 quadrimestral and trimestral periodicities. The days of the week were included via dummy
 201 variables. The trend was considered by including a counter n1 that is equal to 1 on January 1,
 202 2004, 2 on January 2, 2004...n1 =2192 on December 31, 2009.

203 In addition, given that the effect of the independent variables on the dependent variables
 204 could suffer a lag in time, lags were created of up to 5 days for PM₁₀ and NO₂ ; 89 for the case
 205 of ozone, 5 for T_{heat} and 14 for T_{cold} (Arroyo et al., 2016).

206 We used a backwards step modelling process, eliminating those variables that were not
 207 significant at p<0.005.

208 The Poisson modelling allowed for obtaining relative risks (RRP related to each statistically
 209 significant independent variable for increments of 10 µg/m³ for the pollutant variables and of
 210 1°C for the temperature variables.

211 The attributable risks (AR) were calculated based on the RR using Coste and Spira's
212 Equation (Coste & Spira 1991)

213
$$AR = (RR-1)*100/RR.$$

214 The statistical software programs used were SPSS Statistics v.22 (IBM Company) and
215 STATA/SE14.1 (StataCorp LP).

216

3. Results:

3.1 Days with and without Saharan dust advection:

Table 2 shows the number of days with Saharan dust intrusion in each of the regions and the descriptive statistics of the dependent variables for the days with advection of Saharan dust compared to days without advection. The values of days with advection range between 210 for A Coruña (9.6% of days) and 660 for Malaga (30.1%).

In relation to the dependent variables, it is noteworthy that only in the province of Madrid were the total births (TB) more statistically significant on days with dust advection versus days without advection. There was no statistically significant difference between PTB and LBW values between days with and without advection.

Figure 2 shows the comparison between independent variables on days with and without advection of Saharan dust. The PM_{10} values in all cities were higher with statistically significant differences for days with advection vs days without. It is also notable that the NO_2 values were higher in all cities on days with advection versus days without advection (except Seville), although only in four of these cities was the difference statistically significant. In the case of ozone, in all cities, the values for days with advection were higher, and statistically significant, compared to days without advection. The same can be said for the values of T_{max} and T_{min} (except in Las Palmas).

The results of the Poisson modelling related to the incidence of days with and without advection of Saharan dust showed behavior that was clearly different from one case to another, as shown in Table 4.

Related to PTB (Table 4), PM_{10} concentrations appeared significant in the provinces of Malaga and Valencia for lags 2 and 5, while there were high ozone values in A Coruña and Las

Palmas for lags 7 and 1, respectively. Heat is only significant for lag 3 in Las Palmas. The effect of PM_{10} on PTB is only significant in the province of Malaga in lag 3, while heat is statistically significant on two occasions in the cities of Madrid and Seville with short-term effects for lags 2 and 0, respectively. NO_2 is only related to PTB in Las Palmas for lag 0. And finally, and related to LBW, the effect of PM_{10} appears in the provinces of Malaga, Seville and Palma de Mallorca, with short-term effects (lags 0-3), while ozone appears in the provinces of A Coruña and Seville.

From a quantitative perspective, PAR are higher in the case of ozone, followed by those corresponding to T_{heat} y and finally those associated with PM_{10} .

3.2 Days with and without advection of particulate matter from biomass combustion:

In terms of the incidence of the presence of particulate matter from biomass combustion, Table 3 shows that the incidence is much less than the days with intrusion of Saharan dust. Values oscillate between zero days in the Canary Islands Region to 186 in A Coruña (8.5%). The incidence does not give rise to any difference in behavior with respect to the values of the dependent variables of gestation, with the exception of the values of TB in the provinces of Valencia and Balearic Islands, with greater incidence on days without advection from biomass combustion than days *with* advection.

Figure 3 shows that in five of the cities analyzed the days with advection have higher PM_{10} values than do days without advection. The effect of advection with respect to NO_2 is only reflected in statistically significantly higher values for one of the cities and in four cities for the case of ozone. For T_{max} and T_{min} the days with intrusion of particulate matter from biomass consumption are greater than the days without for all of the cities except Bilbao, and these results are statistically significant.

In terms of the impact on variables related to pregnancy analyzed and shown in Table 5, it should be noted that PM_{10} is related to TB in the cities of Zaragoza and Madrid, with short-term effects (lags 1 and 0, respectively). NO_2 is also related to TB in Seville, along with O_{3h} with a more short-term effect in the case of NO_2 (lag 0, compared to 4 for ozone). In the case of PTB, the effect of ozone is related on more occasions than PM_{10} . Thus, O_{3h} appears to be related to PTB in A Coruña (lag 8) and Seville for two lags (lags 4 and 9), while PM_{10} is only associated with PTB in the city of Madrid. The same behavior is observed in relation to LBW, for which there is no association with PM_{10} for days with advection, while there is an association in the case of ozone in A Coruña and Madrid. The impact of heat in lag 2 in Madrid is also worth pointing out. NO_2 is associated with LBW and PTB in the city of Seville.

From a quantitative point of view, behavior is similar to that described above in the case of days with Saharan dust advection. The greatest AR correspond to O_{3h} , followed by T_{heat} and finally the primary pollutants such as NO_2 and PM_{10} .

4. Discussion

The primary result of this study is that the variables related to pregnancy analyzed are influenced by both the existence of Saharan dust intrusion and advection of particulate matter from biomass combustion. The impact of other atmospheric pollutants that are generally not considered in this type of study, such as ozone or levels of NO_2 , as well as the existence of heat waves, have an incidence that is similar to that of PM_{10} particulate matter.

The results shown in Figure 2, which shows that the values of PM_{10} are significantly greater for days with intrusion of Saharan dust compared to those without, highlight the fact that advective of Saharan dust contribute to significantly increasing the levels of PM_{10} of the Mediterranean rim (Querol et al., 2009). This means that the levels of this pollutant increase in an important way, including at urban atmospheric pollutant measurement stations (Salvador et al., 2013).

However, days with intrusion of Saharan dust not only produce a significant increase in the concentrations of PM_{10} , but also NO_2 in cities such as Zaragoza, Madrid, Bilbao and Las Palmas, with statistically significant differences. These results coincide with results found in other studies that analyze the evolution of primary pollutants on days with and without intrusion of Saharan dust in the cities of Barcelona (Pandolfi et al., 2014) and Madrid (Salvador et al., 2019). The reason for this increase, according to these studies, is that the existence of particulate matter on days with Saharan dust intrusion produces a decrease in the incident solar radiation and means that the convective currents diminish, thus the thickness of the mixed layer would diminish (Pandolfi et al., 2014; Salvador et al., 2019) and the concentration of pollutants increases (Li et al., 2017).

A clearer increase is the case of tropospheric ozone, especially in cities with more sunshine, such as Seville, Malaga, Madrid and Zaragoza. In a study carried out in the city of Madrid by Salvador et al., (Salvador et al., 2019) this pollutant was not analyzed, and in

Barcelona (Pandolfi et al., 2014) an increase in ozone was not observed. While it is true that a reduction in the incident solar radiation produced by suspended particles would be detrimental to the formation of ozone (Krupa & Manning 1988), it must be considered that meteorological conditions at a synoptic scale that favor the entry of Saharan dust usually occur in the summer months (Díaz et al., 2017). In these months, tropospheric ozone values are at their maximum and higher in general than for the days without Saharan dust intrusion, which usually occur in the winter months (Díaz et al., 2017). This fact is reinforced by the fact that maximum daily and minimum daily temperatures are higher on days with Saharan dust intrusion than on days without intrusion, as can be seen in Figure 2.

In terms of the descriptive statistics in Figure 3 that show the values of the dependent variables for the days with and without advection of particulate matter from biomass combustion, we can observe that the general frequency of appearance is much lower than for the days with Saharan dust intrusion. This coincides with other research carried out in Spain (Linares et al., 2018). According to the results in the figure, it is clear that the advection of particulate matter from biomass combustion affects the values of PM_{10} concentrations observed in urban air quality control stations (Linares et al., 2018, Ignotti et al., 2010; Analitis et al., 2012). The values of the days with intrusion are greater than the days without intrusion and in five of seven cities (there are two cities with 0 and 1 days with advection of particulate matter) this difference is statistically significant. Although these values are higher than for days without advection, they are far from the values found in other studies (Dennekamp and Abramson 2001; Naeher et al., 2007; **Finlay** et al., 2012) with peaks up to $500 \mu g / m^3$.

Unlike the Saharan dust intrusion days, a statistically significant increase in NO_2 levels was not found for the days with intrusion of particulate matter from biomass combustion except in the city of Palma de Mallorca. This is probably related to the fact that forest fires, for the most part, need wind for their development and propagation (Trigo et al., 2013) which causes

mechanical origin turbulence that would disperse primary pollutants such as NO₂ in an urban atmosphere (Díaz et al., 1999).

In the case of ozone, we see higher values for days with intrusion from biomass combustion than for days without intrusion. These results are consistent with other studies (Linares et al., 2015). The conditions of high insolation and high temperatures that are present in most forest fires could explain these higher ozone concentrations (Azevedo et al 2011; Jaffe et al., 2013).

From the results found up until now, it is clear that an analysis of impact on health for both days with Saharan dust intrusion and advection of particulate matter from biomass combustion cannot be limited exclusively to the increase in particulate matter concentrations or to their synergistic effect on high temperatures (De Sario et al., 2013).

Also it is observed in Table 4 and 5 that both PTB and LBW, almost always behave the same with relation to the studied variables. The main reason to explain this similar behavior is due to more than 60% of births presenting LBW are PTBs, with prematurity being the leading cause of LBW (ACOG, 1995).

There are practically no studies related to the pregnancy variables that analyze days with Saharan dust intrusion. One of the few, carried out in Barcelona (Dadvand et al., 2011), concludes that there is no observable statistically significant effect of episodes of Saharan dust and complications of pregnancy or during birth. The other study, carried out in Guadeloupe, French West Indies (Viel et al., 2019) does find an effect of PM₁₀ on pre-term birth.

The results of this study indicate that, though not in a generalized way, there are cities in which the studied variables seem to be influenced by both PM₁₀ concentrations and high levels of ozone and heat waves. Thus, these variables are risk factors, especially on days with intrusion of Saharan dust.

From a biological point of view, PM_{10} interferes mainly via the respiratory system (Morakinyo et al., 2016), as inhaled particles cross the alveolar barrier, enter the bloodstream and cause oxidative stress (Jauniaux and Burton 2016), and pro-inflammatory (Moller et al., 2014) and pro-thrombotic stress (Martinelli 2013). This produces gestational hypertension (Babisch and Kamp 2009) and placental hypoperfusion, which alters the placental functions and can be the causes of PTB and LBW (Erickson and Arbor 2014). In the case of NO_2 the mechanism is less known but could also be related to oxidative stress described above (Clemente et al., 2016). In the case of high concentrations of ozone, the association with adverse birth outcomes may be related to the decrease in the caliber of the arteries caused by ozone (Park et al., 2005). This could cause an increase in blood pressure in the mother, following a process similar to that of PM. In the case of heat, PM acts as a powerful stressor in pregnant women and clearly influences adverse birth outcomes (Basu et al., 2010; Carolan-Oland et al., 2014).

The lags for which associations are established are coherent with biological mechanisms implicated and described above, indicating a short-term effect of PM_{10} , NO_2 and T_{heat} , followed by process that is delayed in time in the case of ozone. This is in agreement with the behavior of these environmental factors with other health indicators such as daily mortality (Díaz et al., 1999; Díaz et al., 2015).

From a quantitative point of view, the attributable risks related to PM_{10} and NO_2 , and slightly inferior to those obtained in studies that analyze the incidence of these variables at the level of the whole of Spain (Arroyo et al., 2019a,b). This contradicts the synergistic effect described between PM_{10} and high temperatures described in other studies (De Sario et al., 2013). **This does not mean that the attributable cases are less for those days with advection of Saharan dust, because the concentrations of PM_{10} measured are greater, and**

therefore the impact on the number of cases could be higher than that of a day without advection.

On the other hand, the values of RR and RA of T_{heat} are similar to those found in other studies (Arroyo et al., 2016) that analyze the effect of these variables throughout the year. The case of the AR of the high concentrations of ozone is explained by the small number of existing cases of O3h, which causes the confidence interval to be very wide.

Similar behavior is found for days with advection of particulate matter from biomass combustion. There are practically no studies that find a relationship between advection from biomass combustion and adverse birth outcomes. Only one study carried out in Southern California finds an incidence of low birth weight related to the exposure to forest fires, which reaches a decrease of 9g if the exposure was produced in the second trimester of pregnancy (Holstius et al., 2012).

The limitations of this study are those inherent in any ecological longitudinal study. These limitations preclude extrapolating results at the individual level. On the other hand, we used data that were averaged from various measurement stations, and therefore, these measurements do not represent individual exposure. Another bias may be found in the heterogeneity of air pollutant measurement stations, given that the majority are urban stations there are also some background stations. Despite this, the applied methodology is common in this type of study (Samet et al., 2000). These biases are minimized by the inclusion of control variables in the models, such as trend, seasonality and the autoregressive character of the series. Finally, as occurs in all of the studies that analyze the effect of air pollution on existing health variables, there is a problem of misalignment (Gelfand AE, 2010; Barceló et al., 2016).

The results of this study show that days with the natural presence of particulate matter from biomass combustion or from advection of Saharan dust constitute a special risk for

pregnant women. Not only due to the increase in particulate matter, but also because of the existence of other factors associated with these intrusions, including higher concentrations of ozone, high temperatures and in the case of Saharan dust intrusions, the increase in other primary contaminants as a consequence of the decrease in the mixed layer. Public health recommendations should be made in accordance with the findings presented here.

In Spain, Sahara dust advections and the trajectories of biomass combustion can be forecasting in advance. Therefore, measurements in order to reduce emissions from anthropogenic origin could be setting to avoid the total concentrations of pollutants surpassing the WHO guidelines. In this context information messages should be emitted to the vulnerable population, in this case: pregnant women should reduce their exposition to the air pollutants and high temperatures in the central hours of the day.

5. Disclaimer

This paper reports independent results and research. The views expressed are those of the authors and not necessarily those of the Carlos III Institute of Health (*Instituto de Salud Carlos III*).

6. Acknowledgement of funding

The authors gratefully acknowledge Project ENPY 107/18 and Project ENPY 376/18 grants from the Carlos III Institute of Health.

7. References:

- ACOG. American College of Obstetricians and Gynecologists. Preterm labor. ACOG Technical Bulletin, num. 206, June 1995.
- Analitis A, Georgiadis I, Katsouyanni K. Forest fires are associated with elevated mortality in a dense urban setting. *Occup Environ Med* 2012; 69 (3), 158–162 (Mar).
- Arroyo V, Díaz J, Ortiz C, Carmona R, Sáez M, Linares C. Short term effect of air pollution, noise and heat waves on preterm births in Madrid (Spain). *Environ Res* 2016; 145:162-168.
- Arroyo V, Linares C, Díaz J. Premature Births in Spain: Measuring the impact of air pollution using time Series Analysis. *Sci Tot Environ*. 2019a ;660:105-114.
- Arroyo V, Díaz J, Salvador P, Linares C. Impact of Air Pollution on Low Birth Weight in Spain: A National Level Study. *Environ Res* 2019b; 171:69-79.
- Azevedo JM, Gonçalves FL, de Fátima Andrade M. Long-range ozone transport and its impact on respiratory and cardiovascular health in the north of Portugal. *Int J Biometeorol* 2011; 55:187–202.
- Babisch W, Kamp I van. Exposure-response relationship of the association between aircraft noise and the risk of hypertension. *Noise Health* 2009; 11 (44): 161–168.
- Barceló MA, Varga D, Tobias A, Díaz J, Linares C, Saez M. Long term effects of traffic noise on mortality in the city of Barcelona, 2004-2007. *Environ. Res.* 2016, 147, 193-206.**
- Basu R, Malig B, Ostro B. High ambient temperature and the risk of pre-term delivery. *Am J Epidemiol* 2010; 172:1108–1117.
- Carmona R, Díaz J, Mirón IJ, Ortiz C, León I, Linares C. Geographical variation in relative risks associated with cold waves in Spain: The need for a cold wave prevention plan. *Environ Int* 2016; 88:103-111.

449 Carolan-Olah M, Frankowska D. High environmental temperature and preterm birth: are view
450 of the evidence. *Midwifery* 2014; 30(1):50–59.

451 Clemente DBP, Casas M, Vilahur N, et al. Prenatal ambient air pollution, placental
452 mitochondrial DNA content, and birth weight in the INMA (Spain) and ENVIRONAGE (Belgium)
453 birth cohorts. *Environ Health Perspect* 2016; 124 (5): 659–665.

454 Commission Staff Working Paper. Establishing Guidelines for Demonstration and Subtraction
455 of Exceedances Attributable to Natural Sources under the Directive 2008/50/EC on Ambient
456 Air Quality and Cleaner Air for Europe, Brussels, 15.02. 2011. SEC(2011) 208 final, p. 37.
457 http://ec.europa.eu/environment/air/quality/legislation/pdf/sec_2011_0208.pdf .

458 Coste J, Spira A. Le proportion de cas attribuable en Santé Publique: definition(s),estimation(s)
459 et interpretation. *Rev. Epidemiol. Sante Publique* 1991: 51, 399–411.

460 Dadvand P, Basagaña X, Figueras F, Amoly E, Tobias A, de Nazelle A, Querol X, Sunyer J,
461 Nieuwenhuijsen MJ. Saharan dust episodes and pregnancy. *J Environ Monit* 2011
462 Nov;13(11):3222-8.

463 Dennekamp M, Abramson MJ. The effects of bushfire smoke on respiratory health. *Respirology*
464 2011; 16:198–209.

465 De Sario M, Katsouyanni K, Michelozzi P. Climate change, extreme weather events, air
466 pollution and respiratory health in Europe. *Eur Respir J*. 2013; 42(3):826–843.

467 Díaz J, García R, Ribera P, Alberdi JC, Hernández E, PajaresMS. Modeling of Air Pollution and
468 its Relationship with mortality and morbidity in Madrid (Spain). *Int Arch Occup Environ Health*.
469 1999; 72: 366-376.

470 Díaz J, Tobías A, Linares C. Saharan dust and association between particulate matter and case-
471 specific mortality in Madrid (Spain). *Environ Health* 2012; 11.11.

472 Díaz J, Carmona R, Mirón IJ, Ortiz C, León I, Linares C. Geographical variation in relative risks
 473 associated with heat: update of Spain's Heat Wave Prevention Plan. *Environ Int* 2015; 85:273-
 474 283.

475 Díaz J, Linares C, Carmona R, Russo A, Ortiz C, Salvador P, Trigo RM. Saharan dust intrusions in
 476 Spain: health impacts and associated synoptic conditions. *Environ Res* 2017;156: 455-467.

477 Díaz J, Ortiz C, Falcón I, Linares C. Short-term effect of tropospheric ozone on daily mortality in
 478 Spain. *Atm Environ* 2018; 187:107-116.

479 Dibben C, Clemens T. Place of work and residential exposure to ambient air pollution and birth
 480 outcomes in Scotland, using geographically fine pollution climate mapping estimates. *Environ*
 481 *Res* 2015; 140: 535–541.

482 Erickson, A.C., Arbour, L., 2014. The shared pathoetiological effects of particulate air pollution
 483 and the social environment on fetal-placental development . *J Environ Public Health* 2014:
 484 901017.

485 **European Commision 2011.**

486 **http://ec.europa.eu/environment/air/quality/legislation/pdf/sec_2011_0208.pdf.**

487 Finlay SE, Moffat A, Gazzard R, Baker D, Murray V. Health impacts of wildfires. *PLoS Curr* 2012,
 488 4, e4f959951cce2c (Nov 2).

489 **Gelfand AE. Misaligned spatial data: The change of support problem. Handbook of Spatial**
 490 **Statistics; Gelfand AE, Diggle PJ, Fuentes M, Guttorp P, Eds.; Taylor & Francis: Boca Raton,**
 491 **FL, USA, 2010.**

492 Holstius DM, Reid CE, Jesdale BM, Morello-Frosch R. Birth weight following pregnancy during
 493 the 2003 Southern California wildfires. *Environ Health Perspect.* 2012 Sep;120(9):1340-5.

494 Ignotti E, Gonçalves J, Longo KM, Freitas SL, Hacon SS, Netto PA. Impact on human health of
 495 particulate matter emitted from burnings in the Brazilian Amazon region. *Rev Saude Publica*
 496 2010; 44:121–130

497 INE. Instituto Nacional de Estadística, 2019. <https://www.ine.es/>.

498 Ingebrigtsen, R., Steinsland, I., Cirera, L1., Saez, M. Spatially misaligned data and the impact of
 499 monitoring network on health effect estimates (Doctoral thesis at NTNU).In: Ingebrigtsen, R.
 500 (Ed.), *Bayesian Spatial Modelling of Non-stationary Processes and Misaligned Data Utilising*
 501 *Markov Properties for Computational Efficiency*.2015. Norwegian University of Science and
 502 Technology.

503 Jaffe DA, Wigder N, Downey N, Pfister G, Boynard A, Reid SB. Impact of wildfires on ozone
 504 exceptional events in the western U.S. *Environ Sci Technol* 2013; 47 (19): 11065–11072.

505 Jauniaux E, Burton GJ. The role of oxidative stress in placental-related diseases of pregnancy. *J*
 506 *Gynecol Obstet Biol Reprod* 2016; 45 (8): 775–785

507 Jiménez E, Linares C, Martínez D, Díaz J. Role of Saharan dust in the relationship between
 508 particulate matter and short-term daily mortality among the elderly in Madrid (Spain). *Science*
 509 *of Total Environment*.2010; 408:5729-5736.

510 Krupa SV and Manning WJ. Atmospheric ozone: Formation and effects on vegetation. *Env Pol*
 511 1988; 50:101-137.

512 Li Z, Guo J, Ding A, Liao H, Liu J, Sun Y, Wang, T, Xue H, Zhang H, Zhu B. Aerosol and boundary-
 513 layer interactions and impact on air quality. *Nat Sci Rev*2017; 4 (6): 810–833.

514 Linares C, Carmona R, Mirón IJ, Tobías A, Díaz J . Influence of advections of particulate matter
 515 from biomass combustion on specific-cause mortality in Madrid in the period 2004-2009.
 516 *Environ Sci Pol Res* 2015; 22: 7012-7019.

517 Linares C, Carmona R, Salvador P, Díaz J. Impact on mortality of biomass combustion from
 518 wildfires in Spain: a regional analysis. *Sci Tot Environ* 2018; 622-623:547-555.

519 López-Villanueva E, Íñiguez C, Peral N, García MD, Ballester F. Characterizing mortality effects
 520 of particulate matter size fractions in the two capitalcities of the Canary Islands. *Environ*
 521 *Res*2012; 112: 129–138.

522 Martin KL, Hanigan IC, Morgan GG, Henderson SB, Johnston FH. Air pollution from bushfires
 523 and their association with hospital admissions in Sydney, Newcastle and Wollongong, Australia
 524 1994–2007. *Aust N Z J Public Health* 2013; 37 (3): 238–243.

525 Martinelli N, Olivieri O, Girelli D. Air particulate matter and cardiovascular disease: a narrative
 526 review. *Eur J Intern Med* 2013; 24 (4): 295–302.

527 Mirabelli MC, Künzli N, Avol E, Gilliland FD, Gauderman WJ, McConnell R, Peters JM.
 528 Respiratory symptoms following wildfire smoke exposure: airway size as a susceptibility factor.
 529 *Epidemiology*; 2009; 20 (3): 451–459.

530 **MITECO. Ministerio para la Transición Ecológica 2013.**
 531 **[https://www.miteco.gob.es/es/calidad-y-evaluacion-ambiental/temas/atmosfera-y-calidad-](https://www.miteco.gob.es/es/calidad-y-evaluacion-ambiental/temas/atmosfera-y-calidad-del-aire/metodologiaparaepisodiosnaturales-revabril2013_tcm30-186522.pdf)**
 532 **[del-aire/metodologiaparaepisodiosnaturales-revabril2013_tcm30-186522.pdf](https://www.miteco.gob.es/es/calidad-y-evaluacion-ambiental/temas/atmosfera-y-calidad-del-aire/metodologiaparaepisodiosnaturales-revabril2013_tcm30-186522.pdf)**

533 MITECO. Ministerio para la Transición Ecológica 2019. <https://www.miteco.gob.es/es/>.

534 Møller P, Danielsen PH, Karotki DG, et al. Oxidative stress and inflammation generated DNA
 535 damage by exposure to air pollution particles. *Mutat Res Rev Mutat Res*. 2014; 762: 133–166

536 Morakinyo OM, Mokgobu M., Mukhola MS. Health outcomes of exposure to biological and
 537 chemical components of inhalable and respirable particulate matter. *Int J Environ Res Public*
 538 *Health* 2016; 1: 1–22.

539 Naeher LP, Brauer M, Lipsett M, Zelikoff JT, Simpson CD, Koenig JQ et al. Woodsmoke health
540 effects: a review. *Inhal Toxicol* 2007; 19: 67–106.

541 Pandolfi M, Tobias A, Alastuey A, Sunyer J, Schwartz J, Lorente J, Pey J, Querol X. Effect of
542 atmospheric mixing layer depth variations on urban air quality and daily mortality during
543 Saharan dust outbreaks. *Sci Total Environ* 2014 Oct 1;494-495:283-9.

544 Park, S.K., O'Neill, M.S., Vokonas, P.S., Sparrow, D., Schwartz, J. Effects of air pollution on heart
545 rate variability: the VA normative aging study. *Environ Health Perspect* 2005; 113 (3): 304–309.

546 Pedersen M, Giorgis-Allemand L, Bernard C, et al. Ambient air pollution and low birthweight: a
547 European cohort study (ESCAPE). *Lancet Respir Med*. 2013; 1 (9): 695–704.

548 Pérez L, Tobías A, Querol X, Pey J, Alastuey A, Díaz J, Sunyer J. Saharan dust, particulate matter
549 and cause specific mortality: A Case-Crossover study in Barcelona (Spain). *Environ Int* 2012;
550 48:150-155.

551 Querol X, Alastuey A, Pey J, Pandolfi M, Cusack M, Pérez N, Viana M, Moreno T, Mihalopoulos,
552 N, Kallos G, Kleanthous S. African dust contributions to mean ambient PM₁₀ mass-levels across
553 the Mediterranean Basin. *Atmos Environ* 2009; 43 (28): 4266–4277.

554 Reid JS, Hyer, EJ, Prins EM, Westphal DL, Zhang J, Wang J et al. Global monitoring and
555 forecasting of biomass-burning smoke: description of and lessons from the Fire Locating and
556 Modeling of Burning Emissions (FLAMBE) program. *IEEE J Sel Top Appl Earth Obs Remote*
557 *Sens* 2009; 2:144–162.

558 Reyes M, Díaz J, Tobías A, Montero JC, Linares C. Impact of Saharan dust particles on hospital
559 admissions in Madrid. *Int J Environl Health Res* 2014; 24:63-72.

560 Salvador, P., Artíñano, B., Molero, F., Viana, M., Pey, J., Alastuey, A., Querol, X. African dust
 561 contribution to ambient aerosol levels across central Spain: characterization of long-range
 562 transport episodes of desert dust. *Atmos. Res.* 2013; 127, 117–129.

563 Salvador P, Alonso-Pérez S, Pey J, Artíñano B, de Bustos JJ, Alastuey A, Querol X. African dust
 564 outbreaks over the western Mediterranean Basin: 11-year characterization of atmospheric
 565 circulation patterns and dust source areas. *Atmos Chem Phys.* 2014; 14: 6759–6775.

566 Salvador P, Molero F, Fernández AJ, Tobías A, Pandolfi M, et al., Synergistic effect of the
 567 occurrence of African dust outbreaks on atmospheric pollutant levels in the Madrid
 568 metropolitan area. *Atmos Res* 2019; 226:208-218.

569 Samet J, Dominici F, Zeger S, Schwartz J, Dockery D. The National Morbidity, Mortality and Air
 570 Pollution Study, 2000. Part I: Methods and Methodologic Issues. Part I. Report No. 94 Health
 571 Effects Institute, Boston.

572 Samoli E, Kougea E, Kassomenos P, Analitis A. Does the presence of desert dust modify the
 573 effect of PM₁₀ on mortality in Athens, Greece? *Sci Total Environ* 2011; 409 (11), 2049–2054.
 574

575 Stafoggia M, Zauli-Sajani S, Pey J, Samoli E, Alessandrini E, Basagaña X, et al. Desert dust
 576 outbreaks in Southern Europe: contribution to daily PM₁₀ concentrations and short-term
 577 associations with mortality and hospital admissions. *Environ Health Perspect* 2016; 124 (4):
 578 413–419.

579 Stieb DM, Chen L, Eshoul M, Judek S. Ambient air pollution, birth weight and preterm birth: a
 580 systematic review and meta-analysis. *Environ Res* 2012; 117: 100–111.

581 Tobías A, Caylá JA, Pey J, Alastuey A, Querol X. Are Saharan dust intrusions increasing the risk
 582 of Meningococcal meningitis? *Int J Infect Dis* 2011a; 15, e503.

583 Tobías A, Pérez L, Díaz J, Linares C, Pey J, Alastuey A, Querol X. Short-term effects of
 584 particulate matter on total mortality during Saharan dust outbreaks: A Case-Crossover analysis
 585 in Madrid (Spain). *Sci Total Environment* 2011b;412-413:386-389.

586 Trigo RM, Sousa PM, Pereira MG, Rasilla D, Gouveia CM. Modelling wildfire activity in Iberia
 587 with different atmospheric circulation weather types. *Int J Climatol* 2013.
 588 <https://doi.org/10.1002/joc.3749>.

589 Vedal, S., Dutton, S.J. Wildfire air pollution and daily mortality in a large urban area. *Environ.*
 590 *Res.*2006; 102 (1), 29–35 (Sep).

591 Viana, M., Pey, J., Querol, X., Alastuey, A., de Leeuw, F., Lükewille, A. Natural sources of
 592 atmospheric aerosols influencing air quality across Europe. *Sci. Total Environ.* 2014; 72,825–
 593 833.

594 Viel JF, Mallet Y, Raghoumandan C, Quénel P, Kadhel P, Rouget F, Multigner L. **Impact** of
 595 Saharan dust episodes on preterm births in Guadeloupe (French West Indies). *Occup Environ*
 596 *Med.* 2019 May;76(5):336-340

597 Weichenthal, S., Kulka, R., Lavigne, E., van Rijswijk, D., Brauer, M., Villeneuve, P.J., Stieb, D.,
 598 Joseph, L., Burnett, R.T. Biomass burning as a source of ambient fine particulate air pollution
 599 and acute myocardial infarction. *Epidemiology* 2017; 28 (3), 329–337 (May).

City	Cold wave: Daily minimum temperature(°C) $T_{\text{cold threshold}}$	Heat wave: Daily maximum temperature (°C) $T_{\text{heat threshold}}$	Daily Ozone threshold($\mu\text{g}/\text{m}^3$) $O_{3\text{threshold}}$
Bilbao	-2	30	72
Zaragoza	-2	36	72
A Coruña	4	26	71
Madrid	-2	34	60
Málaga	4	40	Without threshold
Sevilla	2	40	95
Valencia	2	34	99
Las Palmas	Without threshold	32	53
Palma de Mallorca	0	36	Without threshold

Table 1. Threshold temperatures for cold waves ($T_{\text{cold threshold}}$) and heat waves ($T_{\text{heat threshold}}$) and daily ozone threshold ($O_{3\text{threshold}}$) for each location analyzed.

Region	City	N	Total Births Mean 95% CI	PTB Mean 95% CI	LBW Mean 95% CI	N	Total Births Mean 95% CI	PTB Mean 95% CI	LBW Mean 95% CI
North	Bilbao	220	8.83 (8.39 9.27)	0.58 (0.47 0.69)	0.62 (0.51 0.73)	1972	8.18 (8.05 8.31)	0.64 (0.60 0.68)	0.61 (0.57 0.65)
North-East	Zaragoza	346	18.99 (16.49 21.49)	1.69 (1.54 1.84)	1.58 (1.43 1.73)	1273	18.50 (18.27 18.73)	1.71 (1.64 1.78)	1.58 (1.51 1.65)
North-West	A Coruña	210	5.62 (5.27 5.97)	0.45 (0.35 0.55)	0.49 (0.39 0.59)	1982	5.62 (5.37 5.87)	0.47 (0.44 0.50)	0.44 (0.41 0.47)
Centre	Madrid	398	95.61* (94.02 97.20)	7.93 (5.59 8.27)	7.25 (6.94 7.56)	1794	92.97 (92.23 93.71)	7.63 (7.48 7.78)	7.05 (6.90 7.20)
South-East	Málaga	660	17.82 (17.47 18.17)	1.65 (1.54 1.76)	1.57 (1.46 1.68)	1532	17.97 (17.73 18.21)	1.60 (1.53 1.67)	1.55 (1.48 1.62)
South-west	Sevilla	554	21.96 (21.54 22.38)	2.04 (1.90 2.18)	1.81 (1.68 1.94)	1638	21.84 (21.59 22.09)	1.90 (1.82 1.98)	1.73 (1.67 1.70)
East	Valencia	481	23.19 (22.53 23.85)	2.04 (1.89 2.19)	2.00 (1.85 2.15)	1711	23.27 (22.94 23.60)	1.89 (1.81 1.97)	1.94 (1.86 2.02)
Canary Islands	Las Palmas	491	9.68 (9.38 9.98)	0.91 (0.82 1.00)	0.79 (0.70 0.88)	1701	9.83 (9.67 9.99)	0.87 (0.82 0.92)	0.85 (0.80 0.90)
Balearic Isles	Palma Mallorca	448	12.23 (11.88 12.58)	1.00 (0.89 1.11)	1.04 (0.93 1.15)	1744	12.04 (11.86 12.22)	0.93 (0.88 0.98)	0.91 (0.86 0.96)

Table 2. Mean values and 95% confidence intervals (95% CI) of total births, premature births (PTB) and low birth weight (LBW) for days with and without advection of Sahara dust according to regions and provincial capitals.

* Statistically significant differences $p < 0.05$

Region	City	N	Total Births Mean 95% CI	PTB Mean 95% CI	LBW Mean 95% CI	N	Total Births Mean 95% CI	PTB Mean 95% CI	LBW Mean 95% CI
North	Bilbao	1	8.00	1.00	1.00	2191	8.24 (8.12 8.36)	0.63 (0.58 0.68)	0.61 (0.56 0.66)
North-East	Zaragoza	17	20.59 (17.16 24.02)	1.59 (1.19 1.99)	1.41 (1.01 1.81)	2175	18.56 (18.35 18.77)	1.71 (1.65 1.77)	1.58 (1.52 1.64)
North-West	A Coruña	186	5.20 (4.85 5.90)	0.42 (0.32 0.52)	0.47 (0.37 0.57)	2006	5.65 (5.53 5.77)	0.44 (0.41 0.47)	0.47 (0.44 0.50)
Centre	Madrid	56	92.17 (87.63 96.71)	7.73 (6.26 9.20)	6.83 (5.39 8.27)	2136	93.48 (92.80 94.16)	7.69 (7.55 7.83)	7.09 (6.96 7.22)
South-East	Málaga	16	18.06 (15.99 20.13)	0.81* (0.37 1.25)	1.00 (0.47 1.53)	2176	17.92 (17.72 18.12)	1.62 (1.56 1.68)	1.56 (1.50 1.62)
South-west	Sevilla	60	22.42 (21.04 23.80)	2.47 (1.98 2.96)	2.17 (1.74 2.60)	2132	21.86 (21.64 22.08)	1.92 (1.85 1.99)	1.74 (1.68 1.80)
East	Valencia	14	19.21 (15.80 22.62)	1.86 (1.04 2.68)	1.71 (0.93 2.49)	2178	23.27* (22.98 23.56)	1.93 (1.86 2.00)	1.96 (1.89 2.03)
Canary Islands	Las Palmas	0				2192	9.80 (9.66 9.94)	0.88 (0.84 0.92)	0.84 (0.80 0.88)
Balearic Isles	Palma Mallorca	2	10.50 (9.53 11.47)	0.50 (0.03 1.47)	0.50 (0.03 1.47)		12.08* (11.92 12.24)	0.93 (0.88 0.98)	0.95 (0.90 1.00)

Tabla 3. Mean values and 95% confidence intervals (95% CI) of the total number of total births, premature births (PTB) and low birth weight (LBW) for days with and without biomass combustion advection according to regions and provincial capitals.

* Statistically significant differences at $p < 0.05$

		Days with adventon			Days without adventon		
Region	Ciudad	Total Births	PTB	LBW	Total Births	PTB	LBW
North	Bilbao				Tcold (7) RR: 1.25 (1.03 1.52) AR: 20.1 (3.2 34.0)	NO2 (2) RR: 1.05 (1.01 1.09) AR:4.9 (1.1 8.5)	PM10 (0) RR: 1.04 (1.00 1.08) AR: 3.5 (0.06 6.8) O3h (1) RR: 1.08 (1.00 1.16) AR: 7.1 (0.3 13.4)
North-East	Zaragoza						
North-West	A Coruña	O3h(7) RR: 1.28 (1.06 1.55) AR:22.0 (5.9 35.4)		O3h(6) RR: 1.65 (1.01 2.72) AR: 39.5 (0.6 63.20)	Tcold (12) RR: 1.15 (1.04 1.27) AR:13.0 (3.8 21.4)	Tcold (12) RR: 1.42 (1.04 1.92) AR : 29.4 (4.3 47.9)	Tcold (12) RR: 1.51 (1.14 1.99) AR : 33.6 (12.2 49.8) O3h(8) RR: 1.22 (1.03 1.44) AR: 17.7 (2.8 30.4)
Centre	Madrid		Theat (2) RR: 1.06 (1.02 1.11) AR: 5.89 (2.0 9.6)			PM10 (0) RR: 1.03 (1.00 1.05) AR: 2.7 (0.4 5.00)	
South-East	Málaga	PM10 (5) RR: 1.01 (1.00 1.01) AR: 0.7 (0.1 1.4)	PM10 (3) RR: 1.02 (1.00 1.04) AR: 2.2 (0.30 4.1)	PM10 (3) RR: 1.03 (1.02 1.05) AR: 3.4 (1.6 5.1)	Tcold (7) RR: 1.06 (1.01 1.10) AR: 5.3 (0.7 9.8)	Tcold (0) RR: 1.16 (1.01 1.32) AR:13.4(1.05 24.2)	
South-west	Sevilla		Theat(0) RR: 1.19 (1.07 1.32) RA: 16.0 (6.6 24.4)	PM10 (1) RR: 1.05 (1.02 1.07) AR: 4.4 (2.0 6.8) O3h(2) RR: 1.12 (1.02 1.23) AR: 10.8 (2.0 18.7)		Theat(1) RR: 1.50 (1.09 2.06) RA: 33.3 (8.4 51.4) Tcold (4) RR: 1.14 (1.04 1.26) AR : 12.6 (3.5 20.8) PM10 (1) RR: 1.03 (1.01 1.05) AR: 3.3 (1.3 5.2)	Theat(1) RR: 1.63 (1.19 2.23) RA: 38.6 (15.8 55.2) Tcold (5) RR: 1.22 (1.11 1.34) AR : 18.1 (10.0 25.4) PM10 (1) RR: 1.03 (1.01 1.05) AR: 2.8 (0.7 4.8)
East	Valencia	PM10 (2) RR: 1.02 (1.00 1.05) AR: 2.3 (0.2 4.4)		Theat(2) RR: 1.19 (1.02 1.40) RA: 16.3 (1.7 28.6)	Tcold (8) RR: 1.08 (1.01 1.15) AR : 7.3 (1.4 12.8)	Theat(0) RR: 1.15 (1.04 1.27) RA: 12.8(3.6 21.1)	Theat(1) RR: 1.11 (1.02 1.20) RA: 9.6 (1.6 17.0)

					NO2 (0) RR: 1.01 (1.00 1.01) AR:0.8 (0.4 1.3) O3h(2) RR: 1.19(1.04 1.36) AR: 16.1 (4.0 26.7)		Tcold (10) RR: 1.33 (1.14 1.55) AR : 24.8 (12.1 35.6) O3h(2) RR: 1.60 (1.07 2.40) AR: 37.6 (6.40 58.4)
Canary Islands	Las Palmas	Theat (3) RR: 1.06 (1.02 1.11) AR: 6.0 (1.8 10.0) O3h(1) RR: 1.12 (1.04 1.21) AR: 10.7 (3.4 17.5)	NO2 (0) RR: 1.16(1.06 1.27) AR:13.7 (5.7 21.1)		O3h(8) RR: 1.05 (1.00 1.10) AR: 4.8 (0.6 8.9)	NO2 (1) RR: 1.06 (1.01 1.12) AR: 5.9 (1.0 10.5)	Theat(1) RR: 1.16 (1.00 1.36) RA: 14.2 (0.0 26.4)
Balearic Isles	Palma Mallorca	Tcold (6) RR: 1.28(1.06 1.55) AR : 22.0 (5.8 35.4)		Tcold (8) RR: 1.32(1.03 1.68) AR : 24.2 (3.1 40.7) PM10 (0) RR: 1.06 (1.03 1.10) AR: 5.9 (2.8 9.0)	Theat(1) RR: 1.32 (1.01 1.72) RA: 24.1 (1.1 41.7) PM10 (0) RR: 1.02 (1.00 1.04) AR: 2.1 (0.4 3.7) NO2 (4) RR: 1.01 (1.00 1.02) AR: 1.2 (0.4 2.0)		

Table 4. Statically significant variables in the Poisson regression models for total number of total births, premature births (PTB) and low birth weight (LBW) for days with and without advection of Sahara dust according to regions and provincial capitals. RR: Relative risk; AR: Attributable risk (%)

		Days with advention			Days without advention		
Region	Ciudad	Total Births	PTB	LBW	Total Births	PTB	LBW
North	Bilbao				Tcold (7) RR: 1.25(1.03 1.51) AR : 19.8 (2.8 33.8)		PM10 (0) RR: 1.03(1.00 1.07) AR: 3.2 (0.2 6.2)
North-East	Zaragoza	PM10 (1) RR: 1.06 (1.02 1.09) AR: 5.4 (2.1 8.5)					PM10 (2) RR: 1.02 (1.00 1.03) AR: 1.6 (0.1 3.2)
North-West	A Coruña		O3h(8) RR: 1.58 (1.20 2.09) AR: 36.8 (16.5 52.2)	O3h(8) RR: 1.41 (1.05 1.90) AR: 29.3 (4.8 47.4)			Tcold (12) RR: 1.42(1.09 1.86) AR : 29.7 (7.9 46.3)
Centre	Madrid	PM10 (0) RR: 1.04 (1.01 1.06) AR: 3.4 (1.5 5.3)	PM10 (1) RR: 1.07 (1.01 1.15) AR: 7.0 (0.7 12.9)	Theat(2) RR: 1.23 (1.10 1.37) RA: 18.5 (9.0 27.0) O3h(3) RR: 1.39(1.01 1.91) AR: 28.2(1.3 47.8)	NO2 (0) RR: 1.01 (1.00 1.02) AR: 0.4 (0.2 0.7)	Theat(1) RR: 1.06 (1.02 1.09) RA: 5.4 (2.3 8.5)	Theat(1) RR: 1.04 (1.00 1.08) RA: 3.9 (0.5 7.2)
South-East	Málaga				Tcold (7) RR: 1.05(1.00 1.09) AR : 4.5 (0.2 8.6) PM10 (5) RR: 1.01 (1.00 1.02) AR: 0.6 (0.1 1.1)	PM10 (3) RR: 1.02 (1.00 1.03) AR: 1.7 (0.2 3.2)	PM10 (3) RR: 1.03 (1.01 1.04) AR: 2.6 (1.1 4.0)
South-west	Sevilla	NO2 (0) RR: 1.04 (1.00 1.08) AR: 4.0 (0.0 7.8) O3h(4) RR: 1.15 (1.04 1.26) AR: 12.8 (4.1 20.8)	NO2 (0) RR: 1.16 (1.03 1.30) AR: 13.8 (3.3 23.2) O3h(4) RR: 1.48 (1.15 1.90) AR: 32.4 (13.0 47.4)	NO2 (0) RR: 1.12 (1.00 1.26) AR: 11.1 (0.5 20.5)		Tcold (4) RR: 1.14(1.04 1.26) AR : 12.4 (3.6 20.5) PM10 (1) RR: 1.03 (1.01 1.04) AR: 2.5 (0.9 4.1)	Tcold (5) RR: 1.22 (1.11 1.33) AR : 17.7 (9.8 25.0) PM10 (1) RR: 1.04(1.02 1.05) AR: 3.5 (1.8 5.0)

			O3h(9) RR: 1.46 (1.09 1.95) AR: 31.4 (8.1 48.7)			O3h(0) RR: 1.11(1.03 1.19) AR: 9.8 (3.2 16.0)	
East	Valencia				Tcold (8) RR: 1.08 (1.02 1.15) AR : 7.4 (1.7 12.7) NO2 (0) RR: 1.01 (1.00 1.01) AR: 0.7 (0.3 1.1) O3h(2) RR: 1.12(1.01 1.24) AR: 10.8 (1.1 19.6)	Theat(0) RR: 1.10 (1.00 1.20) RA: 8.9 (0.3 16.7)	Theat(1) RR: 1.11 (1.02 1.20) RA: 9.5 (1.5 16.9) Tcold (10) RR: 1.32 (1.13 1.54) AR : 24.0 (11.2 35.0)
Canary Islands	Las Palmas				Theat(2) RR: 1.04 (1.01 1.07) RA: 3.5 (0.8 6.1) PM10 (0) RR: 1.01(1.00 1.01) AR: 0.4 (0.0 0.7) PM10 (4) RR: 1.01(1.00 1.01) AR: 0.5 (0.1 0.8)	NO2 (1) RR: 1.08 (1.03 1.12) AR: 7.1 (2.9 11.0)	
Balearic Isles	Palma Mallorca				PM10 (0) RR: 1.02(1.01 1.03) AR: 1.4 (0.5 2.3) NO2 (4) RR: 1.01 (1.00 1.02) AR: 1.0 (0.3 1.8)	PM10 (0) RR: 1.04 (1.01 1.07) AR: 3.9 (0.9 6.9)	PM10 (0) RR: 1.06 (1.03 1.09) AR: 5.6 (2.9 8.1)

Table 5. Significant variables in the Poisson regression models for total number of total births, premature births (PTB) and low birth weight (LBW) for days with and without biomass combustion advection according to regions and provincial capitals. RR: Relative risk; AR: Attributable risk (%)

Figure

[Click here to download Figure: Figures_ok_final.docx](#)

Figure 1. Location of the different study areas and cities in which analysis was conducted.

Figure2. Mean daily concentrations ($\mu g/m^3$) de PM_{10} , NO_2 y O_3 and daily maximum and minimum temperatures ($^{\circ}C$), for analyzed cities. In black colour, days with Saharan dust advection and in red colour without.

Figure 3. Mean daily concentrations ($\mu g/m^3$) de PM_{10} , NO_2 y O_3 and daily maximum and minimum temperatures ($^{\circ}C$), for analyzed cities. In black colour, days with biomass combustion advection and in red colour without.