Heat Waves, Mortality and Adaptation in France

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Abstract

This article assesses the effect of extreme heat on mortality in France for the period 1980-2019, using a new monthly database of French municipalities. By leveraging year-to-year random variations in temperature, I show that extreme heat significantly increases the mortality rate, especially for people aged over 80. However, the impact of heat decreased after the major heatwave of 2003 due to the public and private measures that followed. Days over 30°C are 7 times less deadly for people aged over 80 for the period 2004-2019, compared with the period 1980-2003. The study also highlights the greater vulnerability of people living in densely populated cities, where extreme heat is 2.5 times more deadly for the elderly. Mediterranean municipalities, on the other hand, are more resilient than the rest of France, due to the population's acclimatisation to heat and a higher air-conditioning equipment rate. In fact, days above 30°C has 5.6 times less impact on the overall mortality rate in Mediterranean municipalities compared to the rest of France. Finally, I estimate the future trend of heat-related deaths due to climate change. In the medium term (2041-2070), global warming will multiply by 5 the number of deaths of people aged over 75 due to maximum temperatures above 35°C, if current adaptation methods are not improved and if greenhouse gas concentrations continue to rise at the current rate.

Keywords: Heat waves; mortality; climate change; adaptation

JEL Codes: Q54, I14

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1 Introduction

Extreme temperatures affect the body's ability to maintain thermal balance, which can lead to death, especially among the elderly (Pascal, Wagner, and Corso, 2017; Pascal et al., 2023). Due to climate change, the frequency and intensity of heatwaves are expected to increase (Report of the Intergovernmental Panel on Climate Change), thereby enhancing the health risk for exposed and vulnerable populations. The effect of extreme heat on mortality in the US has been well documented in economic literature, but much less so in the European context, and in France in particular. While the US has experienced a drastic reduction in mortality due to heat waves, mainly as a result of the widespread use of air conditioning (Barreca et al., 2016), in France the equipment rate is much lower (see Figure 8). The aim of this study is to assess the effect of extreme heat on mortality in France over the long term, to examine ways to reduce this impact in the context of climate change and to identify the disruptive effect of the 2003 heatwave.

I build a database of monthly mortality rates for the 34,000 French metropolitan municipalities matched with meteorological data over the period 1980-2019. I construct monthly mortality rates from exhaustive individual mortality data recorded in the "Fichiers décennaux des personnes décédées" from INSEE, the French national statistics office. I use daily weather data (E-OBS data, Copernicus EU) gridded at a fine scale (0.1° x 0.1°) to construct monthly temperature bins. I estimate the causal effect of temperature on mortality by exploiting random year-to-year variation in temperature through the inclusion of municipality-by-month and month-by-year fixed effects. The results are also robust using region-by-year fixed effects to control for regional economic trends that may have an impact on mortality (see appendix). I also include temperature lags in a series of robustness tests, which refute the existence of any harvesting effect i.e. heatwaves do cause excess mortality, and not a short-term displacement of deaths (see section Empirical strategy).

I show a U-shaped relationship between temperature and mortality, a well-identified result in the literature (Deschênes and Greenstone, 2011). I find that an additional day between -10°C to -5°C in the month increases mortality rate by 0.0527 (deaths per 10,000 inhabitants) and a day over 30°C (86°F) increases the mortality rate by 0.274, compared with a day between 15°C to 20°C. The elderly are particularly vulnerable to heatwaves. One day over 30°C increases the mortality rate of people over 80 years old by 4.77.

In addition, I show that this relationship has evolved over time. In fact, the high mortality caused by the major 2003 heatwave in France led to the implementation of a series of monitoring and preventive measures aimed at providing information to the public in the event of a heatwave. The 2003 heatwave has raised awareness among the population and the authorities which contributed to a decline in overall mortality due to heat by a factor of 5, and even by a factor of 7 in the mortality of the elderly associated with extreme heat (+30°C) in the period post-2003. I evaluate the overall effect without disentangling the effect of each factors responsible for this reduction. I estimate that before 2004, 7,868 people aged over 75 died each year due to heat (+20°C), whereas after 2003, 2,489 people died each year in the period after 2003, i.e. a reduction in the number of deaths by a factor of 3.

While France has a very low air-conditioning (AC) equipment rate compared with the United States, the Mediterranean region, which is more frequently exposed to hot weather (Figure 10) is therefore better equipped with AC. In France in 2017, 30% of households in Mediterranean region were equipped with air conditioning, compared with 11% of the overall population (Figure 8), while in the US in 2020 90% of household where equipped According to the Residential Energy Consumption Survey of the U.S. Energy Information Administration (EIA). The current equipment rate in France is in fact comparable to that in the United States in the 1960s (according to Barreca et al. (2016), 12% of household where equipped with AC in US in 1960). As a result of the population's acclimatisation to hot weather and the greater use of AC, over the recent period 2003 to 2019, a day above 30°C has 5.6 times less impact on the overall mortality rate and 58 times less impact on mortality rate of people aged over 80 in Mediterranean municipalities.

This study also shows that people living in densely populated cities are more vulnerable to heatwaves. In fact, the effect of a day above 30°C is 2.5 times higher in urban city compared to other municipality for the elderly. Based on existing literature several factors can explain this effect. High concentrations of air pollutants, higher poverty rates and the urban heat island effect are the suggested explanations, although I do not explicitly test the importance of each.

I also estimate that climate change will multiply by 5 the number of deaths over the age of 75 per year due to maximum temperatures above 35°C in the medium term (2041-2070) if current adaptation measures are not improved and if greenhouse gas concentrations continue to rise at the current rate (scenario RCP 8.5[1]).

This paper contributes to the economic literature on the health effects of extreme temperatures. I build a new database and assess, for the first time in France and over a long period, the causal effect of temperature on mortality. I document how France has managed to drastically reduce the impact of extreme heat since 2003 without the massive spread of air conditioning that has occurred in the US. This assessment is particularly important given

[1]The RCP (Representative Concentration Pathways) scenarios define different trends in greenhouse gas emissions, allowing for different projections of global warming. In this study, I use the most pessimistic scenario, RCP 8.5, which assumes that greenhouse gas concentrations continue to rise at the current rate. RCP scenarios are used in IPCC reports ((IPCC, 2014)).

that the the French and European population is ageing and therefore more sensitive to heat waves.

The remainder of this paper is structured as follows : The following section presents the related literature. Section III describes the data. Section IV presents empirical strategy. Section V presents the results and the robustness tests and the last section concludes.

2 Related Literature

Extreme temperatures affect cognitive performance and accumulation of human capital (Graff Zivin, Hsiang, and Neidell, 2018), productivity (Somanathan et al., 2021) and mortality[2] (Deschênes and Greenstone, 2011). When exposed to abnormally high or low temperatures, the body sets up thermoregulatory mechanisms to become accustomed to the local temperatures, which can require several days/weeks to set up. When temperatures are too extreme, the body is no longer able to thermoregulate itself effectively, leading to sequelae and even death (Pascal, Wagner, and Corso, 2017). In France, epidemiological studies have estimated that between 2014 and 2022, 33,000 people in France died due to heat waves, including 23,000 over the age of 75 (Pascal et al., 2023).

Several economic studies have also assessed the effect of temperatures on mortality and identified effective ways to adapt. The major difference between epidemiological and economic studies lies in the estimation methodology (see Karlsson and Ziebarth (2018); Deschênes (2014)), economists placing special emphasis on causal estimation strategies.

In the US context, Deschênes and Greenstone (2011) show in a seminal study a U-shaped relationship between temperature and mortality rates which is confirmed by a large body of literature in various countries[3]. They use annual mortality data and temperature bins to capture the non-linear effect of temperature and establish a causal relationship by using random year-to-year variations in temperature by including a set of regional and temporal fixed effects. Most recent economic studies rely on this methodology to identify causal impacts of temperature on a variety of outcomes including mortality.

High temperatures increase mortality, but some populations are more sensitive. Heat have a major impact on mortality among the elderly causing cardiovascular problems (Yu, Lei, and Wang, 2019). It also increases the risk of pregnancy loss (Hajdu and Hajdu, 2023).

In addition, some regions are more sensitive to extreme cold than extreme heat, and vice

[2]In an economic assessment of heat waves in France, Adélaïde, Chanel, and Pascal (2022) show that heat waves have a significant economic impact, particularly through mortality, which is modelled in monetary terms.

[3]Carleton et al. (2022), using micro data from 40 countries, show a U-shaped relationship between temperature and mortality.

versa. This phenomenon can be explained by the natural adaptation of the population to the local climate, also known as "acclimatisation" (Hanna and Tait, 2015). Several pieces of evidence point in this direction. Heutel, Miller, and Molitor (2021) show that people living in warm regions of the United States react less to extreme heat in terms of mortality, whereas in colder regions, the reaction to extreme cold is weaker. The impact of temperature therefore depends on the difference between the temperature to which the population is accustomed and the thermal shock (cold or hot) to which it is exposed. Indeed, cold temperatures have a greater effect on mortality in Colombia and Mexico, which are more used to warm temperatures (Sarmiento, 2023; Cohen and Dechezleprêtre, 2022). Meteorological parameters can also influence the effect of temperature. Indeed, Barreca (2012) show that an increase in humidity during periods of high heat is associated with an increase in the mortality in the US.

City characteristics can also influence the effect of extreme heat on mortality. In a recent study in the United States, Chakma, Colmer, and Voorheis (2023) show that heat has a greater effect on mortality in areas that were more densely covered with buildings and pavements and less covered with vegetation. In fact, the concentration of buildings generates a heat surplus known as the urban heat island effect, which results in more deaths. Laaidi et al. (2012) assess the urban heat island effect in Paris and showed that the city cooled more slowly at night compared to less dense municipalities, leading to an increase in mortality. The urban heat island phenomenon maintains densely populated areas at a high temperature with no possibility of cooling at night. Han et al. (2024) use an ecological disaster in Toronto that resulted in the destruction of the tree canopy which lead to an increase in temperature and energy consumption, partly due to increased use of air conditioning.

Studies have identified ways to reduce the impact of extreme temperatures. Barreca et al. (2016) report a long-term reduction in heat-related mortality in the US and show that the spread of air conditioning is largely responsible for this reduction. Other studies have also show that air conditioning can reduce the impact of extreme heat on learning and academic results (Park et al., 2020; Zhang, Chen, and Zhang, 2024). Air conditioning is a source of externalities through the heat it releases into the atmosphere and the pollution generated by the energy needed to operate it, however, it remains an essential tool that is difficult to fully replace when it comes to ensuring thermal comfort (Viguié et al., 2020).

Ability to adapt also depends on income. The poorest are more fatally affected by temperatures (Cohen and Dechezleprêtre, 2022; Carleton et al., 2022). Air conditioning, which seems to be a central way to adapt to extreme heat, is costly in investment and energy. In the United States, during heatwaves, wealthier individuals tend to increase their energy consumption, in particular to use air conditioning while the poorest have less opportunity to do so (Doremus, Jacqz, and Johnston, 2022). Bressler et al. (2021) project the future evolution of mortality for various countries associated with climate change and shows that taking into account the future increase in income reduces mortality, which is partly explained by a greater capacity to invest in adaptation equipment such as air conditioning. There is also evidence that dwelling conditions influence mortality due to hot days in China (Liao et al., 2023). The welfare state, by providing decent living conditions, could therefore act as a policy tool to protect the poorest from the effects of extreme temperatures (Mullins and White, 2020).

3 Data

To assess the impact of extreme heat on mortality, I built a new database at the municipal level by combining mortality and socio-economic data from INSEE, the French national statistics office and Copernicus meteorological data (see Table 1 descriptive statistics). It covers the 34,000 French metropolitan municipalities[4] over the period 1980 - 2019[5].

3.1 Meteorological data

I use E-OBS copernicus meteorological data based on observations from meteorological stations throughout Europe and provide daily data[6] (each observation covers 24 hours) gridded to a fine scale of 0.1° x 0.1°. I use data on the average daily air temperature measured near the surface (°C, height of 2 meters) but also precipitation amount (millimeter), relative humidity (in %) and wind speed (meter/second at 10 metres above the surface) to control for the confounding effect of weather variables on mortality. Measuring the average temperature over 24 hours is interesting in the context of this study, as high temperatures during the day and at night have an impact on mortality. The E-OBS data has the advantage of being available over a long period (since 1950) and of providing fine resolution for the main meteorological variables[7]. I aggregate (average) the gridded data for each of the meteorological variables at municipality level for each day over the period studied 1980-2019. I also use

[4]Several municipalities merged during the period studied. In most cases, it is a simple merger of municipalities, I therefore kept in the database the municipalities after the merger and excluded the formerly autonomous municipalities. In the pre-merger period, I aggregate the data of the municipalities forming the future merger by averaging them. However, mergers and splits are sometimes more complex - see Appendix A for more details.

[5]The data and code will soon be publicly available on github.

[6]It should be noted that the data grid stops a little too early at the coastal limit, resulting in missing data for coastal municipalities, but this is negligible.

[7]In comparison, the widely used Copernicus ERA 5 database has a lower resolution of 0.25° x 0.25° compared to E-OBS, but produces hourly data.

maximum temperature data from the E-obs database (Copernicus) to perform robustness tests. I carry out the same operations for maximum and average temperature data.

For each weather variable, I construct bins of values. Using the daily data, I construct monthly variables that count the number of days when the value belongs to a defined interval. This bins method is widely used in the economic literature and allows to capture non-linear effects of temperature on mortality (Deschênes and Greenstone, 2011). Finally, I compute the proportion of days in each temperature interval in the total number of days in each month for each municipality in each year, then multiply each value by 30 to obtain a total number of days equal to 30 for each month, for the sake of homogeneity[8].

Figure 2 shows the average number of days in each temperature bins in a month. July and August are the hottest months in France. Similarly, the Mediterranean départements have a hotter climate than other regions (Figure 2). Due to climate change, the number of hot days is increasing over time (Figure 2). Figure 1 shows the average number of days in each bins over the year.

I also create a binary heatwave variable which indicates for each month and each year whether the municipality experienced a heatwave. A heatwave is defined as a 24-hour average temperature exceeding 25 degrees for at least three consecutive days. This new indicator provides a better understanding of the effect of continuous exposure to heat (day and night). Temperature intensity is important, as is the duration of the heatwave. France officially defines a heatwave as "a period of intense heat lasting three consecutive days and nights"[9]. Exposure to heat over a continuous period without the possibility of cooling down during the night can have serious consequences for health.

3.2 Mortality data

Using data from INSEE, the French national statistics office, "Fichiers décennaux des personnes décédées depuis 1970", which provides an exhaustive annual census of each individual case of death in France, as well as information such as the date of death, gender, age, municipality and surname and first name of the deceased. However, these data are only really close to being exhaustive and therefore usable from 1980 onwards. Indeed, with the onset of computerization of death records from 1970 to 1980 (particularly from 1970 to 1975), before 1980 the data contains some missing values [10].

These mortality data are matched with census population data to compute mortality

[8]February sometimes has 29 days in leap years. For each municipality in each month, the sum of the days is equal to 30. This means that the number of days in the bins can be decimal numbers.

[9]https://www.gouvernement.fr/risques/canicule-et-vagues-de-chaleur.

[10]https://www.insee.fr/fr/information/4190491.

rates. Census data provides information on the population of each municipality by age and gender, but the census is not carried out every year[11]. We perform a linear interpolation of the population for the years between two censuses[12]. From these mortality data and the INSEE census data I calculate a monthly mortality rate[13] for each municipality from 1980 to 2019. The additional information on deaths also allows me to calculate monthly mortality rates by age group and gender[14].

3.3 Population density

Information on the population density of municipalities is collected from data produced by the Territories Observatory, which is based on INSEE census RP data - historical data[15]. I perform a linear interpolation to simulate the missing observations between two censuses. I thus obtain the yearly population density for all the municipalities over the period 1980-2019, which I match with the mortality and temperature data.

3.4 Air conditioning equipment

I use data on air conditioning equipment rate in France in 2021 provided by Lite, a company specialised in analysing energy consumption data[16], estimated on the basis of individual electricity consumption data for 40,000 households and temperature data. The proportion of households equipped with air conditioning is estimated by assessing the reaction of household electricity consumption to high temperatures (by Lite). These data are aggregated at département level (by Lite). The Mediterranean départements are particularly noteworthy, with higher rates of air-conditioning equipment (Figure 9), which can be explained in part by their greater exposure to high temperatures (Figure 10). Based on this data, I constructed a binary variable that takes the value 1 when the municipality belongs to a département with an air-conditioning equipment rate above 20% (the départements circled in red on the Figure 9).

I also use data from the Family Budget Survey (2011 and 2017) produced by INSEE on household air-conditioning equipment rate by region and income decile. The two data sources show consistent statistics for air conditioning rates, with a higher proportion of

[11]Years available: 1975,1982,1990,1999,2008,2013,2019.
[12]Like Cohen and Dechezleprêtre (2022).
[13]I calculate the monthly mortality rate for the municipality by dividing the number of deaths in a municipality in the month by the population in the municipality in the year
[14]Deaths in age group A/population in age group A.
[15]https://www.observatoire-des-territoires.gouv.fr/densite-de-population
[16]https://www.lite.eco/

households equipped in the Mediterranean region compared to the rest of France (see Figure 8 and Figure 9).

3.5 Climate change data

I use gridded data projecting future temperatures at several horizons according to several climate change scenarios provided by DRIAS and produced by French climate modelling laboratories (IPSL, CERFACS, CNRM). I use data based on the RCP8.5 emissions scenario, a theoretical scenario in which greenhouse gas concentration continue to increase at the current rate. The data used are the number of days in the year when the maximum temperature exceeds 35°C in the grid cells for the near future (2021-2050), the medium future (2041-2070) and the reference period (1976-2005). The data are produced using the ALADIN63 model from météo France and the Centre National de Recherches Météorologiques (CNRM), combined with the ADAMONT bias correction method. I aggregate the gridded data at municipality level by an average. The Figure 11, Figure 12 and Figure 13 plot the data for the different time horizons and show a sharp increase forecast in the number of days with a maximum temperature above 35°C, particularly in the Mediterranean area. Based on this forecast data, I estimate in the following sections the evolution of the number of deaths induced by climate change.

4 Empirical strategy

This section presents the econometric models used to estimate the causal effect of extreme heat on mortality. The econometric strategy used in this paper draws on the seminal studies by Deschênes and Greenstone (2011); Deschênes and Moretti (2009). I also present the specifications used to test the robustness of the results and to control for the mortality displacement effect (the harvesting effect).

4.1 Specification

I estimate the following fixed-effects linear regression model where y is the mortality rate (overall, age-adjusted, gender-adjusted) of municipality c in month m in year t.

$$Y_{cmt} = \theta \cdot T_{cmt} + \beta \cdot C_{cmt} + \mu_{cm} + \delta_{mt} + \varepsilon_{cmt} \tag{1}$$

Θ is a vector of estimated parameters associated with temperature bins T, temperature bin 15-20 °C (59-68°F) is excluded from estimation and used as the reference category. The inclusion of a set of temperature bins allows to estimate the non-linear effect of temperature on mortality (Deschênes and Greenstone, 2011). I also use the monthly heatwave exposure indicator, instead of temperature bins, which is a binary variable for each municipality, each month, each year. β is a vector of parameters associated with meteorological variables C, also split into bins[17] to control for the confounding effect of weather variables on mortality.

The specification also includes a full set of municipality by month μ_{cm} fixed effects and month by year δ_{mt} fixed effects to identify the causal effect of random variations of temperature on mortality rate. Within a given municipality-month, year-to-year temperature variations are random and then uncorrelated to unobserved variable influencing mortality rate. The month by year fixed effect controls for unobserved factors affecting month-year mortality for all municipalities and then control for national shocks to the mortality rate at the month-by-year. In a series of robustness tests I also estimate all the main specifications by including département[18] by year fixed effects to control for regional economic trends that may have an impact on mortality (the results are robust using this type of fixed effect).

Regressions are weighted by population and standard errors are clustered at municipality level.

4.2 Harvesting effect

A heatwave can lead to the premature death of frail people who would have died in the short term even if there had been no heatwave, this effect is know as the harvesting effect. To measure this phenomenon, it is usual to look at whether the mortality rate is abnormally low compared with the average after the heatwave, which would indicate that the heatwave hastened the death of frail people who, theoretically, would have passed away in the short term even without the heatwave. This is why it is also called the displacement effect, because the deaths are not additional deaths caused by the heatwave but deaths displaced in the short term.

Deschênes and Moretti (2009) show in the United States, using daily data, that extreme heat increases mortality rate immediately, followed by a drop in mortality, leading to a zero cumulative effect over the medium term which tends to confirm the importance of the displacement effect. Other recent studies have demonstrated this harvesting effect using daily data, but unlike Deschênes and Moretti (2009), they find that the net effect of high heat remains positive and significant on mortality (White, 2017; Karlsson and Ziebarth, 2018).

[17]Humidity is split into the following bins: 0-20%, 20%-40%,40%-60%, 60%-80%, 80%-100%, the reference bins is 20%-40%. Rain is split into the following bins: 0mm, 0-3mm, 3mm-10mm (reference), 10mm-100mm, more than 100mm. wind bins: 0-3 m/s,3-10 (reference) m/s,10-20m/s, more than 20m/s.

[18]A French regional unit.

I tackle this problem explicitly in a robustness test. The following model estimates the impact of temperatures in N and N-1 on the mortality rate in N.

$$Y_{cmt} = \theta \cdot T_{cmt} + \rho \cdot T_{cmt-1} + \beta \cdot C_{cmt} + \alpha \cdot C_{cmt-1} + \mu_{cm} + \delta_{mt} + \varepsilon_{cmt} \tag{2}$$

In this model, the harvesting effect is observed if high temperatures in N-1 are negatively associated with the mortality rate in N. The size of the harvesting effect depends on the cumulative coefficients of the high temperatures in N and N-1. If the effect of the heat wave in N (positive) is stronger than the effect in N-1 (negative), then the heat wave produces a surplus of deaths and not just a short-term displacement of mortality.

5 Results

5.1 Effects of temperature on mortality

Table 2 presents estimates of the impact of different temperature bins on the total monthly mortality rate and age-specific mortality rate over the whole period 1980-2019. In all specifications I control for the meteorological variables wind, rain, humidity, as well as municipality by month and month by year fixed effects.

Column 1 shows a U-shaped relationship between temperature and total mortality rate (see Figure 3), which is a well-established result in the literature. According to these estimates, one additional day above 30°C (86°F) in a month increases the total mortality rate (deaths per 10,000 inhabitants) by 0.274, compared with a day between 15-20°C. Low temperatures also influence mortality, since 1 day between -10°C and -5°C increases the mortality rate by 0.052.

Column 2-10 shows that the relationship between temperature and mortality is stronger for the elderly, and in particular for the over-80s. The effect of extreme heat is significant from the age of 40, and increases with age. The mortality rate for the over-80s increases by 4.77 per day above 30°C, revealing a clear age-related gradient in sensitivity to extremely high temperatures. Elderly are also sensitive to cold, but to a much lesser extent, since an additional day between -10°C and -5°C increases the mortality rate for people in their 80s by 0.722 compared with a day at 15-20°C.

Heat has a greater effect on mortality and it can be explained by a better adaptation/acclimatisation to low temperatures in France than to high temperatures. There are several reasons for this, such as better heating equipment and much less air conditioning (Figure 8), which can be explained by the greater frequency of cold days below 0 degrees than hot days in France (Figure 1).

Hot days can have deleterious effects on mortality but the main danger lies in the accumulation of hot days during the day and night(Laaidi et al., 2012). I examine Table 4 the impact of exposure to a heatwave (average temperature over 25°C on at least 3 consecutive days) during the month on the mortality rate. According to these estimates, the occurrence of a heatwave in the municipality increases the total mortality rate and the mortality rate for the over-80s by 0.21 and 3.34 respectively during the month, which is consistent with previous results.

5.1.1 Effect of population density on the temperature-mortality relationship

In this section I show that densely populated municipalities are significantly more sensitive to extreme heat. Table 5, column 1 shows that a day above 30°C have a significantly stronger impact on the total mortality rate in the most densely populated cities. An increase of one standard deviation in the logarithm of density (1.285) increases the effect of a day above 30°C on the total mortality rate by 0.0665. Thus a municipality that goes from a density (logarithm) equal to 2.8 (first quartile of the distribution) to 4.4 (3rd quartile) would see the effect of a day above 30°C rise from 0.0397 to 0.122. Regarding extreme cold, large towns are less sensitive overall, although several coefficients show opposite signs. Overall, the results for extreme heat are more robust.

In order to detect threshold effects, instead of using a continuous measure of density, I examine the effect of temperature bins in two sub samples of urban and rural municipalities. Figure 5 shows the effect of temperature bins on the 80+ mortality rate in the sub-samples of municipalities with a population density $>$ 300 inhabitants/km^2 (high density) and a population density $<$ 300 inhabitants/km^2 (low density). This threshold is defined by INSEE in order to separate urban from rural areas[19]. The graph shows that extreme heat has a significant positive effect on mortality for people aged over 80, in both urban and rural areas. It also shows that the effect is significantly stronger in more densely populated cities. A day above 30°C in urban city increases the mortality rate of 80+ by 4.97, while in other municipalities it increases by 1.98.

On the basis of existing studies, high temperatures are responsible for more deaths in dense cities for several possible reasons, although I do not disentangle the relative importance of these factors. First, dense French cities are particularly exposed to high levels of air pollution (Salesse, 2024). Several epidemiological studies have shown that high levels of air pollutants (especially PM10 and O3) increase the effect of high temperatures on mortality. (Rai et al., 2023; Analitis et al., 2014; Scortichini et al., 2018; Chen et al., 2018).

[19]see “La grille communale de densité à 7 niveaux”, insee, https://www.insee.fr/fr/statistiques/6686472

In addition, as discussed in the literature review, income is strongly associated with the ability to adapt to temperatures. The most densely populated cities (central cities) have higher poverty rates (Insee, 2021, 2015), which may partly explain the greater impact of heat waves in these municipalities.

It is also possible that average temperatures in the >30°C bins are higher in large cities due to the urban heat island phenomenon(Chakma, Colmer, and Voorheis, 2023), which explains the higher mortality. Indeed, one of the shortcomings of temperatures bins is that it does not take into account the differences in mean temperature that may exist from one city to another within the >30°C bins.

5.2 Adaptation

5.2.1 The disruptive impact of the 2003 heatwave

In 2003, France experienced a particularly deadly heatwave (Fouillet et al., 2006), leading the public authorities to set up a "National Heatwave Plan" from 2004 to deal with future high-temperature period.

A range of measures have been implemented, including a heatwave monitoring and alert system, leading to local and national measures to limit health risks. In the event of a heatwave alert, the various local authorities initiate measures adapted to the alert level, such as using municipal registers to list people who are vulnerable or isolated, and to organise monitoring of these people during the heatwave. Alerts are also used to spread information to the population, along with recommendations, particularly for isolated and vulnerable people. The scale of the measures is proportional to the severity of the alert, and more drastic measures may be taken in the event of an exceptional heatwave (activity restrictions, etc.[20]). In addition to public monitoring and warning policies, the heatwave of 2003 raised public awareness of the importance of protecting oneself against such events, which can encourage the spread of air conditioning and other adaptation methods. Given this set of interrelated effects, it is difficult to assess the specific effect of public policies on the temperature-mortality relationship. Thus, the aim of this section is to measure the disruptive effect of the 2003 heatwave, without distinguishing the different explanatory channels.

In this study, I evaluate the evolution of the effect of temperature on mortality by comparing estimates in two sub-samples before and after 2003 (Table 3). Columns 1-3-5-7-9 are

[20]For more information on the national heatwave plan and the measures implemented since 2004, see : a description of the 2017 National Heatwave Plan, See also the health recommendations in the National Heatwave Plan issued by the French High Council for Public Health. See Guide Orsec départemental S6 disposition spécifique gestion sanitaire des vagues de chaleur, Direction générale de la santé (DGS). See Santé Publique FRANCE / Heatwave: alert and surveillance system and prevention system 2023.

the model estimates from the subsamples over the period 1980-2003 and columns 2-4-6-8-10 over the period 2004-2019.

The coefficient of temperature above 30°C on the total mortality rate is much higher in the pre-2004 period and even become insignificant in the post-2004 period (Table 3). Overall, all the coefficients of high temperatures on the total mortality rate are lower after 2003. A day with a mean temperature above 30°C significantly increases (at the 1% threshold) the total monthly mortality rate by 0.31 (deaths per 10,000 inhabitants) compared with a day between 15°C to 20°C, in the pre-2004 period (Figure 4).

I also show a decrease in the impact of extreme heat on mortality among the elderly (col 3-6), although the coefficients of days above 30°C remain significant in the post-2003 period. A day above 30°C significantly increases the mortality rate of the over-80s by 6.347 before 2004 and by 0.8679 after 2003 (Figure 4), i.e. an impact divided by 7.

In appendix, I carry out estimations with interaction effects between temperatures and a year variable to estimate the significance of the differences in coefficients between the two periods (Table A1). It shows that the effect of hot weather tends to decrease over time.

5.2.2 The effect of extreme heat in the Mediterranean region: air conditioning and acclimatisation

In this section, I show that municipalities in the Mediterranean region are more resistant to extreme heat. The Mediterranean population is better equipped with air conditioning (Figure 8) and is also better acclimatised to high temperatures by being exposed to heat more frequently (Figure 10), thus developing greater physiological resistance. However, I do not distinguish the specific effect of each of these two factors.

Air conditioning is the main method of adaptation in the US and the most effective against extreme heat (Barreca et al., 2016). Figure 9 shows the air-conditioning equipment rate in France in 2021[21] and clearly shows a relatively high equipment rate in the Mediterranean départements. Figure 8 shows the air-conditioning equipment rate by region based on Family Budget survey data produced by INSEE. The two sources of data show completely consistent results. According to the INSEE data, 30% of households were equipped with air conditioning in the Mediterranean region in 2017, compared to 11% of households in whole France Figure 8. This higher equipment rate can be explained by the higher frequency of hot days in this area (Figure 10). When the climate tends to be frequently very hot or very cold, households invest more in specific means of adaptation to the local temperature. These départements are not only currently the most exposed to high temperatures (Figure 10), but also the most exposed to rising temperatures caused by climate change (Figure 13).

[21]Lite data, see data section.

Table 6, I test whether the effect of heat is weaker in Mediterranean region over the recent period 2003 to 2019[22]. Mediterranean is a binary variable which takes the value 1 if the municipality belongs to a department which has a rate of air conditioning equipment higher than 20%. The departments selected in the binary variable are circled in red on the Figure 9. In all specifications, the impact of very hot weather is significantly lower in the Mediterranean region. One day over 30°C increases the mortality rate of people aged over 80 by 5.83 in non Mediterranean departments, compared with 0.1 in Mediterranean departments (i.e. an effect 58 times lower). These results suggest that the elderly in particular are much more resistant to heatwaves in the Mediterranean region and air conditioning and acclimatisation to the local temperature may explain this effect.

Air conditioner requires a significant investment that not all households can afford. Figure 7 shows the percentage of households equipped with air conditioning in 2011 and 2017, by income decile. Air conditioning equipment rate in France has increased, but only slightly, from 9.2% to 11.1% of households between 2011 and 2017[23]. This rate is very low compared with the United States, with almost 90% of households in the US equipped with air conditioning in 2020[24]. In France, the difference in equipment according to income is significant: while 7% of the poorest households are equipped, 16.5% of the richest households are equipped in 2017, and this gap of around 10 percentage points is fairly stable over the period Figure 7.

Air conditioning raises environmental and social issues related to environmental justice (Figure 7). Indeed dependence on air conditioning leads to increased energy consumption in the residential sector (Deschênes and Greenstone, 2011) and its production lead to pollution and CO2 emissions (Deschenes, 2022). Air conditioning is nonetheless a highly effective tool that would be difficult to ignore (Viguié et al., 2020). However, it should be used sparingly and combined with a mix of other solutions highlighted in this study such as reducing air pollution and implementing monitoring and prevention policies.

5.3 Robustness

5.3.1 Harvesting effect

Table 7, I test whether the main specifications are subject to harvesting effect (see the section on empirical strategy) by including a lag for each temperature bins (Equation 2). If there is a harvesting effect in the estimates then the temperature lag variables should have a negative

[22] I am only assessing this effect for recent years, due to the lack of historical data on air conditioning equipment.

[23] Les dépenses des ménages en 2011 et 2017 Enquête Budget de famille - Insee Résultats.

[24] Residential Energy Consumption Survey by U.S. Energy Information Administration (EIA).

effect on mortality.

Column 1 shows that the temperature of the previous month does not significantly influence the mortality rate of the current month, while at the same time the temperatures of the current month significantly influence mortality. Some temperature lag coefficients are even positive and significant, which indicates an additional delayed effect of temperature on mortality.

These results show that the estimations are not affected by the harvesting effect. The aggregation of data at monthly level avoids this problem. In fact, several pieces of evidence show that extreme temperatures only have an effect on mortality in the 30 days following the event (White, 2017).

5.3.2 Additional fixed effects

In the appendix, I estimate all the main specifications by including region (Département) by year fixed effects to control for regional economic trends that may have an impact on mortality[25]. In all specifications (appendix : Region by year fixed effects), the results are consistent and even stronger (in terms of both coefficients and significance) than previous specifications.

To control for any omitted variables that might influence the heat-mortality relationship and that are correlated with density, Table 8 I include a heatwave x municipality by month[26] interaction. This allows to control for the difference in sensitivity to heatwaves across municipalities and thus control for all the unobservable variables that could affect resistance to heatwaves. This allows to capture the effect of high temperatures on mortality by municipality density, independently of other adaptation factors that could alter the strength of the temperature-mortality relationship. I also include a heatwave x year by month interaction that captures the effect of parameters that affect the overall resistance of municipalities to heatwaves over time. The results are consistent with previous estimates. High temperatures are significantly more deadly in the most densely populated cities.

Table 9 reports the results from the same type of model to test the robustness of the effect of belonging to a Mediterranean municipality on the temperature-mortality relationship. The results are also robust, as high temperatures have a smaller impact on mortality in

[25]Except for the specification including the interaction with the Mediterranean region because of perfect collinearity.

[26]I include a conventional interaction effect. I estimate the effect of municipality by month, the interaction municipality by month x heatwave and the heatwave variable. In a standard estimate, one category of municipality by month x heatwave would be excluded as a reference. In this specification, I don't exclude any of these categories, but I do exclude the binary heatwave variable as a reference, which is exactly the same. This choice of reference is imposed by the fixest package on R. In the end, I estimate municipality by month and municipality by Month x heatwave.

the Mediterranean départements, even after controlling for the difference in sensitivity of municipalities to heatwaves induced by unobservable variables. Thus, these specifications capture the causal effect of density as well as the effect of belonging to a Mediterranean region on the temperature-mortality relationship.

5.3.3 Maximum temperature

As a robustness test, Table 10 and Table 11 I estimate the effect of maximum temperatures instead of average temperatures on the different mortality rates. The results are perfectly consistent with the previous results. I find a U-shaped relationship between temperature and mortality (Figure 14), and the coefficients for hot weather are stronger for the elderly and the effect of extreme heat is weaker after 2003 (Figure 15).

5.4 Heat-related deaths

Using the previously estimated coefficients of temperatures on mortality (the dose-response functions[27]) for each temperature bins (estimates Table 3), the frequency of days in each bins[28] and data on the population by age in each municipality, I compute the number of temperature-related deaths in each municipality.

Table 13, first column shows the estimated annual number of deaths over 75 years old associated with each temperature bins based on the pre-2003 temperature coefficients and using the frequency of days in each bins based on the period 2015-2019 [29]. Table 13, Column 2 reports the number of deaths using the dose-response functions for the recent post-2003 period. The differences in the number of deaths between columns 1 and 2 measure the number of deaths avoided due to post-2003 adaptation measures, assuming a fixed population level and a fixed number of days in each bins (compute on period 2015-2019). Not only are the over-75s less likely to die from high temperatures, they are also significantly less likely to die from low temperatures. According to these estimates, 106 people over the age of 75 die every year as a result of temperatures above 30°C. Without the adaptation measures implemented

[27] The "dose-response function" relates to the coefficients of the temperature bins on the mortality rate. 1 day in temperature bins X (dose) generates Y additional deaths (response). The coefficients for the temperature bins are the same across municipalities. However, there are differences in sensitivity between municipalities that I do not take into account, which will bias the estimates of total deaths.

[28] For each municipality I calculate the average annual number of days over the period 2015-2019 in each temperature bins.

[29] For each municipality, for each bin, I do the following calculation: (bin coefficient / 10,000) x number of days in the bin x population over 75. In this way, I find the number of deaths associated with each bin for each municipality, and then sum the total number of deaths for all municipalities for each bin. The bin coefficients used are from regression on mortaliy rate among 75+. I also use the average annual number of days over the period 2015-2019 in each temperature bin in each municipality and data on population over 75 in each municipality to compute number of deaths each municipality.

since 2003, the annual death toll would have reached 700. Overall, the number of deaths over the age of 75 each year due to temperature (cold or heat) has halved since 2003, from 33,167 to 15,432. These estimates make it possible to measure the effect of adaptation on the number of deaths, but they do not take into account the variation in the number of hot days induced by climate change, which also affects the number of deaths. I look at the mortality among the elderly rather than overall mortality because the elderly are most affected by temperatures.

An epidemiological study in France has suggested that the heatwave of 2006 was less deadly as a result of preventive measures put in place after the 2003 heatwave (Fouillet, Rey, and al., 2008). The study compares the actual number of deaths in 2006 due to heat waves with the number of deaths expected from a poisson regression model using data from 1975-2003. The paper shows that in 2006, according to these estimates, 6,452 deaths where expected (including 5,080 aged 75+), but there where only 2,065 heat-related deaths (including 1,254 aged 75+), i.e. divided by 3 (divided by 4 for 75+). Another epidemiological study shows that between 2014 and 2022, 33,000 people in France died due to heat waves, including 23,000 over the age of 75 (Pascal et al., 2023) i.e. 2,555 deaths per year over 75[30]. In this study, I estimate that before 2004, 7,868 people[31] over the age of 75 died each year because of heat (+20°C), whereas after 2003, 2,489 people died each year i.e. heat sensitivity divided by 3. The estimates of the number of deaths are quite consistent with (Pascal et al., 2023)'s estimates.

Although the impact of extreme heat on mortality tends to decrease over time, climate change will lead to an increase in the number of extreme hot days (Figure 12). I use the most recent dose-response function (post-2003) to estimate the future number of deaths using future estimates of the frequency of hot days. In terms of the number of deaths, the adaptation effect could be outweighed by the climate change effect. The Drias provides gridded data on the number of days per year where the maximum temperature exceeds 35°C, based on several climate change scenarios (I use the RCP8.5 scenario where GHG concentration continue to increase at the current rate (see Data section3).

Table 12 reports the number of deaths over the age of 75 induced by maximum temperatures above 35°C[32] . I vary the number of days above 35°C in each municipality according to three time periods: the reference period, the near future and the medium future. Due to climate change, the number of hot days increases over time (Figure 13), leading to an increase in the number of deaths (Table 12). At constant population and with the level of

[30]i.e. 23,000/9.

[31]i.e. the sum in table 13 of deaths caused by temperatures above 20°C.

[32]For each municipality I perform the following calculation: (temperature coefficient /10,000) * population * number of days over 35°C in period t.

adaptation post-2003[33], each year 156 people aged over 75 would have died from maximum temperatures above 35, if the temperatures were those of the reference period, compared with 516 per year for temperatures in the near future. In the medium term, 772 people over the age of 75 will die each year due to maximum temperatures over 35°C, under the assumption that the temperature response functions are homogeneous across all the municipalities (Table 12).

It should be pointed out that the estimation of deaths due to maximum temperature is underestimated because I do not compute the number of deaths induced in the lower bins due to a lack of data on the future frequency of days in these bins. Table 12 nevertheless allows to measure the evolution of the impact of the increase in the number of extremely hot days (max +35°C) on the number of deaths rather than a precise estimation of the total number of deaths. Global warming leads to a sharp rise in the annual number of deaths, as the number of deaths increases by 231% from the reference period to the near-horizon period, and by 50% from the near-horizon period to the medium-horizon period. Overall, the number of deaths per year over the age of 75 will be multiplied by 5 from the reference period (1976-2005) to the medium term (2041-2070) as a result of climate change if current adaptation measures remain fixed.

[33] The post-2003 dose-response function is identical for all municipalities.

6 Conclusion

This study examines the effect of temperature on mortality in France using municipal data over the period 1980-2019. By exploiting the random year-to-year variation in temperature, I show a U-shaped relationship between temperature and mortality and that the elderly, especially those over 80, are also much more sensitive to heat. In addition, I estimate that the impact of heat on mortality decreased significantly after the 2003 heat wave, which led to the implementation of public warning and prevention policies, although this study does not assess the extent to which the policies are responsible for this reduction.

I also show the slight increase in the use of air conditioning in France, although it is much less widespread than in the United States. While air conditioning has been shown to be highly effective in reducing heat-related mortality, it is not a sustainable solution due to environmental problems such as pollution and heat it generates. In addition, air conditioning raises issues of environmental justice, as its accessibility depends on income. Alternative adaptation strategies need to be explored, particularly through the transformation of densely populated cities, which I have shown are more vulnerable to heat waves. A combination of adaptation methods must be considered and made available to all. Future studies should examine how to protect the most economically disadvantaged within and between countries that are less able to protect themselves from heatwaves and climate change.

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Tables

Table 1: Descriptive statistics

Statistic	N	Mean	St. Dev.	Min	Max
Mortality rates					
mortality rate total	16,093,459	3.739	14.891	0.000	8,262.688
mortality rate men	16,093,076	4.115	21.352	0.000	8,150.188
mortality rate women	16,092,230	3.381	18.287	0.000	8,418.843
mortality rate 0 9	15,817,339	0.209	13.482	0.000	10,000.000
mortality rate 10 19	15,839,953	0.263	15.002	0.000	10,000.000
mortality rate 20 39	16,044,133	0.708	17.475	0.000	10,000.000
mortality rate 40 59	16,072,045	1.793	23.351	0.000	10,000.000
mortality rate 60 64	15,629,947	4.058	68.496	0.000	10,000.000
mortality rate 65 69	15,534,533	5.504	79.701	0.000	10,000.000
mortality rate 70 74	15,259,647	9.458	116.072	0.000	10,000.000
mortality rate 75 79	15,110,231	14.308	146.598	0.000	10,000.000
mortality rate 80 plus	15,194,688	41.738	240.870	0.000	10,000.000
Max Temperature bins					
temp max bin < - 10°C	16,093,459	0.005	0.131	0.000	18.214
temp max bin -10 to 0 °C	16,093,459	0.526	1.887	0.000	30.000
temp max bin 0 to 10 °C	16,093,459	6.954	8.753	0.000	30.000
temp max bin 10 to 15 °C	16,093,459	6.669	6.386	0.000	30.000
temp max bin 15 to 20 °C	16,093,459	6.251	5.823	0.000	30.000
temp max bin 20 to 25 °C	16,093,459	5.436	5.945	0.000	30.000
temp max bin 25 to 30 °C	16,093,459	3.096	4.759	0.000	30.000
temp max bin 30 to 35 °C	16,093,459	0.961	2.533	0.000	30.000
temp max bin plus 35 °C	16,093,459	0.101	0.651	0.000	23.226
Temperature bins					
< - 20 °C	16,093,459	0.00005	0.010	0.000	4.839
- 20 to - 15 °C	16,093,459	0.002	0.071	0.000	10.714
- 15 to - 10 °C	16,093,459	0.025	0.342	0.000	19.655
- 10 to - 5 °C	16,093,459	0.178	0.978	0.000	24.643
- 5 to 0 °C	16,093,459	1.252	3.008	0.000	29.032
0 to 5 °C	16,093,459	4.204	5.768	0.000	30.000
5 to 10 °C	16,093,459	7.332	7.156	0.000	30.000
10 to 15 °C	16,093,459	7.384	6.719	0.000	30.000
15 to 20 °C	16,093,459	6.573	7.696	0.000	30.000
20 to 25 °C	16,093,459	2.722	5.186	0.000	30.000
25 to 28 °C	16,093,459	0.292	1.254	0.000	30.000
28 to 30 °C	16,093,459	0.030	0.324	0.000	17.419
> 30 °C	16,093,459	0.004	0.110	0.000	9.677
Weather variables					
humidity bin < 20	15,664,044	0.00002	0.001	0.000	0.387
humidity bin 20 - 40	15,664,044	0.002	0.013	0.000	0.607
humidity bin 40 - 60	15,664,044	0.064	0.118	0.000	0.968
humidity bin 60 - 80	15,664,044	0.403	0.231	0.000	1.000
humidity bin > 80	15,664,044	0.531	0.286	0.000	1.000
rain bin 0 - 3	16,093,459	0.134	0.088	0.000	0.679
rain bin 3 - 10	16,093,459	0.170	0.100	0.000	0.733
rain bin 10 - 100	16,093,459	0.066	0.063	0.000	0.645
rain bin >100	16,093,459	0.00005	0.001	0.000	0.100
rain bin 0	16,093,459	0.630	0.165	0.032	1.000
wind bin 0 - 3	16,070,222	0.562	0.251	0.000	1.000
wind bin 3 - 10	16,070,222	0.437	0.250	0.000	1.000
wind bin 10 - 20	16,070,222	0.001	0.011	0.000	0.821
wind bin > 20	16,070,222	0.00000	0.0002	0.000	0.258
Others					
heatwave (binary)	16,093,459	0.029	0.169	0	1
density	16,093,459	143.939	670.718	0.054	27,419.920

Table 2: Effect of temperature on mortality

Dependent Variables:	Mortality rate (total)	Mortality rate 80+	Mortality rate 75-79	Mortality rate 70-74	Mortality rate 65-69	Mortality rate 60-64	Mortality rate 40-59	Mortality rate 20-39	Mortality rate 10-19	Mortality rate 0-9
Model:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Variables										
< -20 to -15 °C	0.0363	1.024	-0.0384	-0.3996	0.8250***	0.4634**	0.0150	-0.0192	0.0559*	-0.0447
	(0.0628)	(1.101)	(0.6047)	(0.4683)	(0.2510)	(0.2283)	(0.0630)	(0.0308)	(0.0316)	(0.0351)
-15 to -10 °C	-0.0006	0.4364	0.3390	0.1661	-0.1479	0.0353	0.0207	-0.0013	-0.0119*	-0.0063
	(0.0506)	(0.4778)	(0.2557)	(0.1476)	(0.0983)	(0.0827)	(0.0307)	(0.0094)	(0.0062)	(0.0139)
-10 to -5 °C	0.0527**	0.7222***	0.2073**	0.1062*	0.0637	0.0740**	0.0198	0.0028	-0.0050**	-0.0058
	(0.0221)	(0.1747)	(0.0885)	(0.0598)	(0.0399)	(0.0356)	(0.0132)	(0.0039)	(0.0024)	(0.0054)
-5 to 0 °C	0.0237	0.5377***	0.1330**	0.0553	0.0470*	0.0443**	0.0038	-0.0024	-0.0006	-0.0047
	(0.0156)	(0.1244)	(0.0610)	(0.0348)	(0.0258)	(0.0220)	(0.0088)	(0.0022)	(0.0013)	(0.0034)
0 to 5 °C	0.0181*	0.2709***	0.0503	0.0141	0.0310*	0.0211	0.0033	-0.0023	-0.0016	-0.0033
	(0.0107)	(0.0858)	(0.0440)	(0.0255)	(0.0181)	(0.0162)	(0.0063)	(0.0016)	(0.0010)	(0.0026)
5 to 10 °C	0.0054	0.1005**	-0.0083	-0.0016	0.0211*	0.0105	-0.0007	-0.0011	-0.0005	-0.0006
	(0.0041)	(0.0476)	(0.0283)	(0.0169)	(0.0114)	(0.0096)	(0.0034)	(0.0010)	(0.0008)	(0.0016)
10 to 15 °C	0.0014	0.0445	-0.0103	-0.0054	0.0050	0.0005	-0.0005	0.0001	-0.0003	-0.0005
	(0.0026)	(0.0309)	(0.0186)	(0.0114)	(0.0081)	(0.0066)	(0.0023)	(0.0007)	(0.0006)	(0.0011)
20 to 25 °C	0.0155**	0.2276***	0.0685***	0.0459**	0.0478***	0.0257**	0.0068*	0.0008	0.0009	0.0019
	(0.0074)	(0.0610)	(0.0244)	(0.0191)	(0.0128)	(0.0101)	(0.0041)	(0.0011)	(0.0009)	(0.0016)
25 to 28 °C	0.0411***	0.6323***	0.2409***	0.1230***	0.0921***	0.0801***	0.0286***	0.0034**	-3.24×10^{-8}	0.0014
	(0.0062)	(0.0840)	(0.0459)	(0.0307)	(0.0205)	(0.0159)	(0.0049)	(0.0017)	(0.0017)	(0.0021)
28 to 30 °C	0.0895***	1.082***	0.4717***	0.2367***	0.1475***	0.1290***	0.0532***	0.0083*	0.0011	0.0050
	(0.0217)	(0.2015)	(0.1063)	(0.0749)	(0.0536)	(0.0372)	(0.0149)	(0.0046)	(0.0037)	(0.0064)
> 30 °C	0.2743***	4.770***	1.001***	0.6689***	0.5055***	0.3836***	0.1004***	0.0037	-0.0096	0.0046
	(0.0537)	(0.6697)	(0.2639)	(0.1723)	(0.1114)	(0.0818)	(0.0309)	(0.0106)	(0.0081)	(0.0149)
Controls										
Wind	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
rain	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
humidity	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fixed-effects										
Municipality by Month	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year by Month	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of Fixed-effects										
Municipality by Month	402 672	400 991	400 992	401 580	402 011	402 180	402 672	402 576	402 216	402 214
Year by Month	480	480	480	480	480	480	480	480	480	480
Fit statistics										
Observations	15,641,050	14,765,824	14,685,286	14,832,998	15,098,287	15,190,167	15,620,028	15,592,949	15,394,086	15,371,374
R^2	0.64551	0.40511	0.29630	0.24660	0.23139	0.18461	0.27802	0.04383	0.03028	0.11111
Within R^2	0.00013	8.07×10^{-5}	2.63×10^{-5}	1.57×10^{-5}	1.52×10^{-5}	1.6×10^{-5}	2.23×10^{-5}	2.21×10^{-6}	2.03×10^{-6}	8.95×10^{-6}

Note: Table reports OLS estimates. The dependent variable is mortality rate. Clustered (Municipality) standard-errors in parentheses. Regressions are weighted by population. *p<0.1; **p<0.05; ***p<0.01.

Table 3: Effect of temperature on mortality in 1980-2003 and 2004-2019

Dependent Variables:	Mortality rate (total)		Mortality rate 80+		Mortality rate 75-79		Mortality rate men		Mortality rate women	
Model:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Variables										
< -20 to -15 °C	0.0711	0.0739	1.489	0.8777	0.1129	-0.4583	0.0995	0.1360	0.0428	0.0108
	(0.0483)	(0.0979)	(1.107)	(1.459)	(0.6131)	(0.9193)	(0.0644)	(0.1432)	(0.0590)	(0.1049)
-15 to -10 °C	0.0131	0.0490**	0.4034	0.4633	0.3761	0.3783*	0.0207	0.0589*	0.0058	0.0385
	(0.0320)	(0.0242)	(0.4322)	(0.3379)	(0.2941)	(0.1954)	(0.0378)	(0.0322)	(0.0309)	(0.0297)
-10 to -5 °C	0.0553***	0.0460***	0.8541***	0.4479***	0.2461***	0.1748*	0.0491***	0.0490***	0.0607***	0.0434***
	(0.0131)	(0.0121)	(0.1626)	(0.1537)	(0.0939)	(0.0896)	(0.0160)	(0.0148)	(0.0125)	(0.0134)
-5 to 0 °C	0.0312***	0.0256***	0.6797***	0.3382***	0.1661***	0.0876*	0.0242***	0.0241***	0.0374***	0.0270***
	(0.0064)	(0.0071)	(0.0984)	(0.1057)	(0.0539)	(0.0512)	(0.0082)	(0.0085)	(0.0062)	(0.0075)
0 to 5 °C	0.0172***	0.0256***	0.3185***	0.2877***	0.0621	0.0640*	0.0143**	0.0258***	0.0194***	0.0257***
	(0.0049)	(0.0042)	(0.0733)	(0.0665)	(0.0423)	(0.0348)	(0.0061)	(0.0054)	(0.0049)	(0.0048)
5 to 10 °C	0.0053	0.0108***	0.1259	0.1201**	-0.0096	0.0092	0.0029	0.0128***	0.0074	0.0089**
	(0.0059)	(0.0033)	(0.0798)	(0.0510)	(0.0349)	(0.0275)	(0.0064)	(0.0043)	(0.0060)	(0.0036)
10 to 15 °C	0.0016	0.0052**	0.0811**	0.0658*	-0.0038	0.0120	-0.0008	0.0071**	0.0037	0.0035
	(0.0025)	(0.0023)	(0.0398)	(0.0365)	(0.0222)	(0.0185)	(0.0031)	(0.0030)	(0.0025)	(0.0026)
20 to 25 °C	0.0165***	0.0042*	0.2154***	0.0684*	0.0282	0.0394**	0.0146**	0.0002	0.0183***	0.0081***
	(0.0061)	(0.0025)	(0.0634)	(0.0360)	(0.0259)	(0.0196)	(0.0070)	(0.0033)	(0.0056)	(0.0028)
25 to 28 °C	0.0473***	0.0151***	0.7333***	0.1990***	0.2628***	0.0915**	0.0468***	0.0153**	0.0478***	0.0152***
	(0.0105)	(0.0053)	(0.1342)	(0.0664)	(0.0509)	(0.0420)	(0.0118)	(0.0069)	(0.0102)	(0.0059)
28 to 30 °C	0.0972***	0.0450***	1.262***	0.4494***	0.2223	0.4713***	0.0957***	0.0419**	0.0996***	0.0477***
	(0.0209)	(0.0127)	(0.2602)	(0.1555)	(0.1465)	(0.0951)	(0.0241)	(0.0178)	(0.0223)	(0.0137)
> 30 °C	0.3137***	0.0649	6.347***	0.8679**	1.061***	0.4732*	0.2463***	0.0841	0.3779***	0.0496
	(0.0634)	(0.0464)	(0.9348)	(0.4035)	(0.3522)	(0.2583)	(0.0584)	(0.0573)	(0.0747)	(0.0481)
Controls										
Wind	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
rain	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
humidity	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fixed-effects										
Municipality by Month	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year by Month	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fit statistics										
Observations	9,397,238	6,243,812	8,804,965	5,960,859	8,858,043	5,827,243	9,396,953	6,243,716	9,396,511	6,243,320
R^2	0.65572	0.73588	0.40227	0.57361	0.32265	0.38300	0.54830	0.66660	0.51601	0.63010
Within R^2	0.00019	6.38×10^{-5}	0.00011	3.33×10^{-5}	2.33×10^{-5}	1.53×10^{-5}	9.31×10^{-5}	4.01×10^{-5}	0.00013	5.13×10^{-5}

Note: Table reports OLS estimates. The dependent variable is mortality rate. Clustered (Municipality) standard-errors in parentheses. Regressions are weighted by population.
*p<0.1; **p<0.05; ***p<0.01.

Table 4: Effect of a heatwave on mortality

Dependent Variables:	Mortality rate (total)	Mortality rate 80+	Mortality rate 75-79	Mortality rate 70-74	Mortality rate 65-69	Mortality rate 60-64	Mortality rate 40-59	Mortality rate 20-39	Mortality rate 10-19	Mortality rate 0-9
Model:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Heatwave (binary)	0.2103^{***}	3.342^{***}	1.022^{***}	0.3089^{**}	0.3499^{***}	0.2302^{***}	0.1037^{***}	0.0232^{**}	0.0152	0.0077
	(0.0331)	(0.3781)	(0.2258)	(0.1452)	(0.1065)	(0.0720)	(0.0238)	(0.0094)	(0.0096)	(0.0132)
Controls										
Wind	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
rain	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
humidity	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fixed-effects										
Municipality by Month	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year by Month	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fit statistics										
Observations	15,641,050	14,765,824	14,685,286	14,832,998	15,098,287	15,190,167	15,620,028	15,592,949	15,394,086	15,371,374
R^2	0.64549	0.40508	0.29629	0.24659	0.23139	0.18460	0.27801	0.04383	0.03027	0.11111
Within R^2	6.55×10^{-5}	2.6×10^{-5}	1.1×10^{-5}	7.36×10^{-6}	4.24×10^{-6}	5.07×10^{-6}	8.98×10^{-6}	1.28×10^{-6}	1.16×10^{-6}	6.71×10^{-6}

Note: Table reports OLS estimates. The dependent variable is mortality rate. Clustered (Municipality) standard-errors in parentheses. Regressions are weighted by population. $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$.

Table 5: Effect of temperature on mortality and population density

Dependent Variables:	Mortality rate (total)	Mortality rate 80+	Mortality rate 75-79	Mortality rate men	Mortality rate women
Model:	(1)	(2)	(3)	(4)	(5)
Variables					
< -20 to -15 °C	0.4331***	1.974	-1.559	0.4042*	0.4640***
	(0.1584)	(2.693)	(1.648)	(0.2148)	(0.1531)
-15 to -10 °C	0.2600***	1.220*	0.0670	0.3175***	0.2040***
	(0.0588)	(0.7375)	(0.5882)	(0.0696)	(0.0574)
-10 to -5 °C	0.0081	0.5016	-0.2757	0.0118	0.0053
	(0.0462)	(0.3862)	(0.1858)	(0.0510)	(0.0433)
-5 to 0 °C	0.0927***	0.5285**	-0.0222	0.0979***	0.0876***
	(0.0326)	(0.2549)	(0.1142)	(0.0359)	(0.0302)
0 to 5 °C	0.0558**	0.5076***	-0.0828	0.0619**	0.0498**
	(0.0248)	(0.1945)	(0.0880)	(0.0272)	(0.0229)
5 to 10 °C	0.0283	0.0664	-0.0429	0.0303	0.0262
	(0.0203)	(0.1598)	(0.0681)	(0.0223)	(0.0188)
10 to 15 °C	0.0093	-0.0717	-0.0404	0.0088	0.0097
	(0.0093)	(0.0903)	(0.0406)	(0.0104)	(0.0086)
20 to 25 °C	-0.0085**	-0.1756***	0.0808**	-0.0134***	-0.0034
	(0.0040)	(0.0631)	(0.0382)	(0.0050)	(0.0043)
25 to 28 °C	0.0260	0.0408	0.2065*	0.0255	0.0275
	(0.0496)	(0.3443)	(0.1143)	(0.0549)	(0.0454)
28 to 30 °C	-0.1098**	-3.236***	-1.310***	-0.0812	-0.1368**
	(0.0518)	(0.6517)	(0.3368)	(0.0536)	(0.0579)
> 30 °C	-0.1053	-5.686**	-1.438*	0.0118	-0.2077
	(0.1361)	(2.416)	(0.8157)	(0.1182)	(0.1688)
log(density)	-2.956***	15.76***	10.39***	-3.180***	-2.756***
	(0.3477)	(4.525)	(1.912)	(0.3844)	(0.3212)
< -20 to -15 °C × log(density)	-0.0853***	-0.2507	0.3328	-0.0691	-0.1018***
	(0.0311)	(0.6607)	(0.3752)	(0.0441)	(0.0301)
-15 to -10 °C × log(density)	-0.0430***	-0.1644	0.0364	-0.0511***	-0.0351***
	(0.0085)	(0.1539)	(0.1032)	(0.0106)	(0.0085)
-10 to -5 °C× log(density)	0.0095*	0.0354	0.0826***	0.0089	0.0099**
	(0.0049)	(0.0588)	(0.0300)	(0.0054)	(0.0049)
-5 to 0 °C × log(density)	-0.0107***	-0.0056	0.0213	-0.0120***	-0.0094***
	(0.0030)	(0.0345)	(0.0171)	(0.0033)	(0.0029)
0 to 5 °C × log(density)	-0.0058**	-0.0432	0.0193	-0.0069**	-0.0048*
	(0.0026)	(0.0266)	(0.0131)	(0.0029)	(0.0025)
5 to 10 °C × log(density)	-0.0037	0.0041	0.0046	-0.0041	-0.0034
	(0.0030)	(0.0261)	(0.0103)	(0.0032)	(0.0028)
10 to 15 °C × log(density)	-0.0013	0.0173	0.0043	-0.0013	-0.0013
	(0.0013)	(0.0142)	(0.0063)	(0.0014)	(0.0012)
20 to 25 °C × log(density)	0.0041***	0.0630***	-0.0026	0.0046***	0.0036***
	(0.0013)	(0.0132)	(0.0059)	(0.0014)	(0.0012)
25 to 28 °C × log(density)	0.0035	0.0859	0.0019	0.0039	0.0029
	(0.0082)	(0.0587)	(0.0167)	(0.0090)	(0.0075)
28 to 30 °C × log(density)	0.0330***	0.6749***	0.2790***	0.0289***	0.0369***
	(0.0068)	(0.1039)	(0.0554)	(0.0071)	(0.0082)
> 30 °C × log(density)	0.0518**	1.443***	0.3240**	0.0290	0.0724**
	(0.0253)	(0.4557)	(0.1482)	(0.0212)	(0.0310)
Controls					
Wind	Yes	Yes	Yes	Yes	Yes
rain	Yes	Yes	Yes	Yes	Yes
humidity	Yes	Yes	Yes	Yes	Yes
Fixed-effects					
Municipality by Month	Yes	Yes	Yes	Yes	Yes
Year by Month	Yes	Yes	Yes	Yes	Yes
Fit statistics					
Observations	15,641,050	14,765,824	14,685,286	15,640,669	15,639,831
R^2	0.64630	0.40525	0.29646	0.56015	0.52148
Within R^2	0.00235	0.00032	0.00026	0.00150	0.00146

Note: Table reports OLS estimates. The dependent variable is mortality rate. Clustered (Municipality) standard-errors in parentheses. Regressions are weighted by population. *p<0.1; **p<0.05; ***p<0.01.

Table 6: Effect of temperature on mortality by region

Dependent Variables:	Mortality rate (total)	Mortality rate 80+	Mortality rate 75-79	Mortality rate men	Mortality rate women
Model:	(1)	(2)	(3)	(4)	(5)
Variables					
< -20 to -15 °C	0.0166	0.5770	-0.7361	0.0433	-0.0109
	(0.0964)	(1.483)	(0.9064)	(0.1332)	(0.1062)
-15 to -10 °C	0.0571**	0.5218	0.4004**	0.0596*	0.0536*
	(0.0239)	(0.3296)	(0.1953)	(0.0321)	(0.0290)
-10 to -5 °C	0.0469***	0.4904***	0.1510*	0.0467***	0.0471***
	(0.0118)	(0.1567)	(0.0886)	(0.0148)	(0.0129)
-5 to 0 °C	0.0257***	0.3337***	0.0819*	0.0222***	0.0290***
	(0.0069)	(0.1043)	(0.0497)	(0.0084)	(0.0074)
0 to 5 °C	0.0282***	0.3237***	0.0602*	0.0254***	0.0308***
	(0.0041)	(0.0650)	(0.0342)	(0.0052)	(0.0047)
5 to 10 °C	0.0124***	0.1410***	0.0182	0.0129***	0.0117***
	(0.0033)	(0.0497)	(0.0269)	(0.0043)	(0.0038)
10 to 15 °C	0.0067***	0.0876**	0.0197	0.0078**	0.0058**
	(0.0024)	(0.0369)	(0.0191)	(0.0031)	(0.0027)
20 to 25 °C	0.0092***	0.1007***	0.0589***	0.0054	0.0129***
	(0.0026)	(0.0371)	(0.0210)	(0.0035)	(0.0031)
25 to 28 °C	0.0098	0.0444	-0.0058	0.0119	0.0081
	(0.0060)	(0.0861)	(0.0462)	(0.0076)	(0.0069)
28 to 30 °C	0.1136***	1.613***	0.6558***	0.0997***	0.1264***
	(0.0162)	(0.2492)	(0.1330)	(0.0189)	(0.0185)
> 30 °C	0.3373***	5.833***	1.200***	0.2510***	0.4194***
	(0.0574)	(0.9284)	(0.3092)	(0.0512)	(0.0695)
< -20 to -15 °C × Mediterranean (binary)	2.890	-4.944	-31.04***	6.231*	-0.8238
	(2.548)	(26.22)	(11.91)	(3.590)	(1.653)
-15 to -10 °C × Mediterranean (binary)	-0.0596	2.490	0.5581	-0.4067*	0.2693
	(0.2500)	(2.555)	(2.027)	(0.2396)	(0.4069)
-10 to -5 °C× Mediterranean (binary)	0.0722	0.8399	-0.7393*	0.0337	0.1249*
	(0.0541)	(0.7817)	(0.3935)	(0.0760)	(0.0725)
-5 to 0 °C × Mediterranean (binary)	0.0466**	0.6048**	-0.0012	0.0324	0.0592**
	(0.0210)	(0.2641)	(0.1073)	(0.0227)	(0.0247)
0 to 5 °C × Mediterranean (binary)	-0.0078	-0.1774	-0.0657	-0.0062	-0.0084
	(0.0080)	(0.1290)	(0.0602)	(0.0092)	(0.0093)
5 to 10 °C × Mediterranean (binary)	0.0024	0.0115	-0.1118***	-0.0031	0.0083
	(0.0055)	(0.0903)	(0.0428)	(0.0068)	(0.0065)
10 to 15 °C × Mediterranean (binary)	-0.0003	-0.0724	-0.0592	-0.0002	6.15×10^{-5}
	(0.0044)	(0.0542)	(0.0364)	(0.0060)	(0.0053)
20 to 25 °C × Mediterranean (binary)	-0.0048	-0.0003	-0.0242	-0.0084	-0.0017
	(0.0040)	(0.0456)	(0.0319)	(0.0054)	(0.0049)
25 to 28 °C × Mediterranean (binary)	0.0070	0.1810	0.0955*	-0.0004	0.0140
	(0.0093)	(0.1165)	(0.0523)	(0.0104)	(0.0108)
28 to 30 °C × Mediterranean (binary)	-0.0781***	-1.282***	-0.4091**	-0.0717**	-0.0839***
	(0.0225)	(0.3144)	(0.1658)	(0.0312)	(0.0237)
> 30 °C × Mediterranean (binary)	-0.2769***	-5.731***	-1.131***	-0.1643*	-0.3814***
	(0.0945)	(1.267)	(0.4142)	(0.0999)	(0.1041)
Controls					
Wind	Yes	Yes	Yes	Yes	Yes
rain	Yes	Yes	Yes	Yes	Yes
humidity	Yes	Yes	Yes	Yes	Yes
Fixed-effects					
Municipality by Month	Yes	Yes	Yes	Yes	Yes
Year by Month	Yes	Yes	Yes	Yes	Yes
Fit statistics					
Observations	6,577,667	6,278,968	6,145,813	6,577,559	6,577,151
R^2	0.73371	0.56646	0.38269	0.66396	0.62719
Within R^2	0.00018	0.00020	3.45×10^{-5}	7.26×10^{-5}	0.00019

Note: Table reports OLS estimates. The dependent variable is mortality rate. Clustered (Municipality) standard-errors in parentheses. Regressions are weighted by population. *p<0.1; **p<0.05; ***p<0.01.

Table 7: Estimation of the harvesting effect

Dependent Variables:	Mortality rate (total)	Mortality rate 80+	Mortality rate 75-79	Mortality rate men	Mortality rate women
Model:	(1)	(2)	(3)	(4)	(5)
Variables					
< -20 to -15 °C	0.0341	0.8803	-0.0104	0.0932	-0.0244
	(0.0573)	(1.113)	(0.6141)	(0.0685)	(0.0655)
-15 to -10 °C	0.0051	0.3828	0.3548	0.0182	-0.0079
	(0.0464)	(0.4711)	(0.2681)	(0.0523)	(0.0436)
-10 to -5 °C	0.0505***	0.6479***	0.1930**	0.0514***	0.0494***
	(0.0165)	(0.1482)	(0.0802)	(0.0197)	(0.0148)
-5 to 0 °C	0.0230*	0.5053***	0.1220**	0.0202	0.0252**
	(0.0118)	(0.1043)	(0.0537)	(0.0136)	(0.0106)
0 to 5 °C	0.0182**	0.2530***	0.0510	0.0177*	0.0184**
	(0.0082)	(0.0733)	(0.0392)	(0.0095)	(0.0075)
5 to 10 °C	0.0070**	0.1062**	-0.0038	0.0067*	0.0070**
	(0.0032)	(0.0466)	(0.0254)	(0.0040)	(0.0031)
10 to 15 °C	0.0026	0.0468	-0.0078	0.0020	0.0031
	(0.0020)	(0.0290)	(0.0169)	(0.0025)	(0.0020)
20 to 25 °C	0.0140**	0.2250***	0.0682***	0.0120*	0.0160***
	(0.0059)	(0.0515)	(0.0214)	(0.0067)	(0.0053)
25 to 28 °C	0.0403***	0.6279***	0.2313***	0.0418***	0.0392***
	(0.0058)	(0.0789)	(0.0427)	(0.0067)	(0.0058)
28 to 30 °C	0.0892***	1.072***	0.4385***	0.0908***	0.0880***
	(0.0235)	(0.2084)	(0.1046)	(0.0274)	(0.0221)
> 30 °C	0.2675***	4.726***	0.9157***	0.2222***	0.3118***
	(0.0536)	(0.6752)	(0.2661)	(0.0544)	(0.0587)
< -20°C_lag	0.0109	0.3511	1.182	0.1166	-0.1282
	(0.2142)	(3.809)	(3.649)	(0.3361)	(0.3250)
-20 to -15 °C_lag	-0.0216	0.1919	-0.0711	-0.0275	-0.0149
	(0.0652)	(1.019)	(0.8039)	(0.0822)	(0.0748)
-15 to -10 °C_lag	-0.0068	0.6924	0.2750	-0.0021	-0.0115
	(0.0391)	(0.4245)	(0.2109)	(0.0444)	(0.0371)
-10 to -5 °C_lag	0.0386**	0.5625***	0.1517*	0.0289	0.0475***
	(0.0164)	(0.1539)	(0.0858)	(0.0191)	(0.0152)
-5 to 0 °C_lag	0.0061	0.2771***	0.0610	0.0007	0.0110
	(0.0114)	(0.1013)	(0.0544)	(0.0132)	(0.0104)
0 to 5 °C_lag	0.0088	0.1854**	0.0389	0.0049	0.0124*
	(0.0081)	(0.0736)	(0.0405)	(0.0093)	(0.0075)
5 to 10 °C_lag	0.0032	0.0917*	-0.0067	0.0019	0.0043
	(0.0034)	(0.0502)	(0.0250)	(0.0042)	(0.0034)
10 to 15 °C _lag	0.0011	0.0570*	0.0111	0.0012	0.0010
	(0.0028)	(0.0296)	(0.0184)	(0.0034)	(0.0026)
20 to 25 °C _lag	0.0060	0.0314	0.0212	0.0065	0.0054
	(0.0078)	(0.0646)	(0.0242)	(0.0086)	(0.0073)
25 to 28 °C _lag	0.0082	0.0209	0.1172***	0.0152**	0.0014
	(0.0052)	(0.0700)	(0.0403)	(0.0062)	(0.0053)
28 to 30 °C_lag	0.0358	0.2144	0.2290**	0.0503	0.0226
	(0.0296)	(0.2665)	(0.1075)	(0.0324)	(0.0283)
> 30 °C_lag	0.0048	0.1068	-0.2599	0.0031	0.0048
	(0.0485)	(0.4476)	(0.2001)	(0.0548)	(0.0465)
Controls					
Wind	Yes	Yes	Yes	Yes	Yes
rain	Yes	Yes	Yes	Yes	Yes
humidity	Yes	Yes	Yes	Yes	Yes
LAG Wind	Yes	Yes	Yes	Yes	Yes
LAG rain	Yes	Yes	Yes	Yes	Yes
LAG humidity	Yes	Yes	Yes	Yes	Yes
Fixed-effects					
Municipality by Month	Yes	Yes	Yes	Yes	Yes
Year by Month	Yes	Yes	Yes	Yes	Yes
Fit statistics					
Observations	15,304,358	14,448,225	14,369,628	15,303,980	15,303,151
R^2	0.64631	0.40458	0.29633	0.56034	0.52138
Within R^2	0.00023	9.72×10^{-5}	3.48×10^{-5}	0.00013	0.00017

Note: Table reports OLS estimates. The dependent variable is mortality rate. Clustered (Municipality) standard-errors in parentheses. Regressions are weighted by population. *p<0.1; **p<0.05; ***p<0.01.

Table 8: Effect of temperature on mortality, density and additional controls

Dependent Variables:	Mortality rate (total)	Mortality rate 80+
Model:	(1)	(2)
Variables		
< -20 to -15 °C	0.4356***	2.007
	(0.1585)	(2.728)
-15 to -10 °C	0.2614***	1.236*
	(0.0577)	(0.7443)
-10 to -5 °C	0.0091	0.5113
	(0.0444)	(0.3847)
-5 to 0 °C	0.0933***	0.5321**
	(0.0306)	(0.2506)
0 to 5 °C	0.0563**	0.5115***
	(0.0228)	(0.1899)
5 to 10 °C	0.0288	0.0688
	(0.0182)	(0.1549)
10 to 15 °C	0.0094	-0.0704
	(0.0077)	(0.0886)
20 to 25 °C	-0.0109***	-0.2255***
	(0.0042)	(0.0607)
25 to 28 °C	-0.0133	-0.3106
	(0.0490)	(0.4165)
28 to 30 °C	-0.1364	-3.488***
	(0.0888)	(0.8603)
> 30 °C	-0.1266	-5.708**
	(0.1510)	(2.462)
log(density)	-2.953***	15.90***
	(0.3610)	(4.629)
< -20 to -15 °C × log(density)	-0.0856***	-0.2562
	(0.0314)	(0.6699)
-15 to -10 °C × log(density)	-0.0430***	-0.1664
	(0.0087)	(0.1561)
-10 to -5 °C× log(density)	0.0095*	0.0347
	(0.0049)	(0.0595)
-5 to 0 °C × log(density)	-0.0106***	-0.0062
	(0.0029)	(0.0347)
0 to 5 °C × log(density)	-0.0057**	-0.0438
	(0.0026)	(0.0267)
5 to 10 °C × log(density)	-0.0036	0.0038
	(0.0029)	(0.0260)
10 to 15 °C × log(density)	-0.0012	0.0171
	(0.0012)	(0.0143)
20 to 25 °C × log(density)	0.0044***	0.0702***
	(0.0009)	(0.0109)
25 to 28 °C × log(density)	0.0076	0.1053
	(0.0075)	(0.0718)
28 to 30 °C × log(density)	0.0333***	0.6567***
	(0.0118)	(0.1422)
> 30 °C × log(density)	0.0524*	1.368***
	(0.0275)	(0.4627)
Controls		
Wind	Yes	Yes
rain	Yes	Yes
humidity	Yes	Yes
Fixed-effects		
Municipality by Month	Yes (402,672)	Yes (400,991)
Year by Month	Yes (480)	Yes (480)
Varying Slopes		
heatwave (binary) X (Municipality by Month)	Yes (402,672)	Yes (400,991)
heatwave (binary) X (Year by Month)	Yes (480)	Yes (480)
Fit statistics		
Observations	15,641,050	14,765,824
R^2	0.65009	0.40847
Within R^2	0.00229	0.00028

Note: Table reports OLS estimates. The dependent variable is mortality rate. Clustered (Municipality) standard-errors in parentheses. Regressions are weighted by population. *p<0.1; **p<0.05; ***p<0.01.

Table 9: Effect of temperature on mortality by region and additional controls

Dependent Variables:	Mortality rate (total)	Mortality rate 80+
Model:	(1)	(2)
Variables		
< -20 to -15 °C	0.0191	0.6111
	(0.0996)	(1.536)
-15 to -10 °C	0.0590**	0.5376
	(0.0246)	(0.3394)
-10 to -5 °C	0.0478***	0.4932***
	(0.0121)	(0.1619)
-5 to 0 °C	0.0262***	0.3288***
	(0.0071)	(0.1075)
0 to 5 °C	0.0286***	0.3169***
	(0.0042)	(0.0676)
5 to 10 °C	0.0128***	0.1336***
	(0.0034)	(0.0516)
10 to 15 °C	0.0071***	0.0781**
	(0.0024)	(0.0382)
20 to 25 °C	0.0079***	0.0851**
	(0.0028)	(0.0391)
25 to 28 °C	-0.0032	-0.0917
	(0.0076)	(0.1109)
28 to 30 °C	0.0643***	0.7412**
	(0.0191)	(0.3102)
> 30 °C	0.2807***	4.318***
	(0.0641)	(0.9995)
< -20 to -15 °C × Mediterranean (binary)	2.885	-4.994
	(2.631)	(27.12)
-15 to -10 °C × Mediterranean (binary)	-0.0632	2.443
	(0.2583)	(2.645)
-10 to -5 °C× Mediterranean (binary)	0.0733	0.8688
	(0.0557)	(0.8070)
-5 to 0 °C × Mediterranean (binary)	0.0443**	0.5759**
	(0.0216)	(0.2725)
0 to 5 °C × Mediterranean (binary)	-0.0082	-0.1744
	(0.0083)	(0.1339)
5 to 10 °C × Mediterranean (binary)	0.0023	0.0168
	(0.0057)	(0.0935)
10 to 15 °C × Mediterranean (binary)	-0.0003	-0.0654
	(0.0045)	(0.0560)
20 to 25 °C × Mediterranean (binary)	-0.0041	0.0021
	(0.0044)	(0.0485)
25 to 28 °C × Mediterranean (binary)	0.0094	0.1216
	(0.0117)	(0.1746)
28 to 30 °C × Mediterranean (binary)	-0.0434*	-0.7136**
	(0.0249)	(0.3433)
> 30 °C × Mediterranean (binary)	-0.2418**	-4.717***
	(0.1012)	(1.391)
Controls		
Wind	Yes	Yes
rain	Yes	Yes
humidity	Yes	Yes
Fixed-effects		
Municipality by Month	Yes (399,035)	Yes (394,809)
Year by Month	Yes (204)	Yes (204)
Varying Slopes		
heatwave (binary) X (Municipality by Month)	Yes (399,035)	Yes (394,809)
heatwave (binary) X (Year by Month)	Yes (204)	Yes (204)
Fit statistics		
Observations	6,577,667	6,278,968
R^2	0.73910	0.57361
Within R^2	0.00011	9.15×10^{-5}

Note: Table reports OLS estimates. The dependent variable is mortality rate. Clustered (Municipality) standard-errors in parentheses. Regressions are weighted by population. *p<0.1; **p<0.05; ***p<0.01.

Table 10: Effect of maximum temperature on mortality

Dependent Variables:	Mortality rate (total)	Mortality rate 80+	Mortality rate 75-79	Mortality rate men	Mortality rate women
Model:	(1)	(2)	(3)	(4)	(5)
Variables					
max < -10 to 0 °C	0.0264*	0.4171***	0.2079***	0.0279	0.0250*
	(0.0148)	(0.1392)	(0.0669)	(0.0172)	(0.0132)
max 0 to 10 °C	0.0064	0.1121*	0.0690**	0.0072	0.0055
	(0.0049)	(0.0592)	(0.0318)	(0.0058)	(0.0045)
max 10 to 15 °C	-0.0018	-0.0017	0.0005	-0.0003	-0.0033
	(0.0032)	(0.0400)	(0.0159)	(0.0034)	(0.0034)
max 20 to 25 °C	0.0011	-0.0438	-5.14×10^{-5}	0.0013	0.0010
	(0.0025)	(0.0338)	(0.0182)	(0.0032)	(0.0024)
max 25 to 30 °C	0.0114	0.0796	0.0156	0.0101	0.0125*
	(0.0084)	(0.0761)	(0.0333)	(0.0097)	(0.0074)
max 30 to 35 °C	0.0329***	0.3482***	0.1177**	0.0333***	0.0325***
	(0.0098)	(0.1127)	(0.0552)	(0.0116)	(0.0086)
max > 35 °C	0.1142***	1.163***	0.4083***	0.1127***	0.1163***
	(0.0392)	(0.2951)	(0.1238)	(0.0437)	(0.0360)
Controls					
Wind	Yes	Yes	Yes	Yes	Yes
rain	Yes	Yes	Yes	Yes	Yes
humidity	Yes	Yes	Yes	Yes	Yes
Fixed-effects					
Municipality by Month	Yes	Yes	Yes	Yes	Yes
Year by Month	Yes	Yes	Yes	Yes	Yes
Fit statistics					
Observations	15,641,050	14,765,824	14,685,286	15,640,669	15,639,831
R^2	0.64551	0.40509	0.29629	0.55952	0.52082
Within R^2	0.00012	4.63×10^{-5}	2.06×10^{-5}	7.24×10^{-5}	8.91×10^{-5}

Note: Table reports OLS estimates. The dependent variable is mortality rate. Clustered (Municipality) standard-errors in parentheses. Regressions are weighted by population. *p<0.1; **p<0.05; ***p<0.01.

Table 11: Effect of maximum temperature on mortality in recent years (2004 to 2019)

Dependent Variables:	Mortality rate (total)	Mortality rate 75+
Model:	(1)	(2)
Variables		
max < -10 to 0 °C	0.0243***	0.1809**
	(0.0087)	(0.0754)
max 0 to 10 °C	0.0118***	0.0872***
	(0.0037)	(0.0323)
max 10 to 15 °C	0.0027	0.0195
	(0.0025)	(0.0214)
max 20 to 25 °C	-0.0027	-0.0241
	(0.0022)	(0.0210)
max 25 to 30 °C	-0.0031	0.0070
	(0.0035)	(0.0337)
max 30 to 35 °C	0.0042	0.0762
	(0.0060)	(0.0517)
max > 35 °C	0.0376***	0.3398***
	(0.0098)	(0.0756)
Controls		
Wind	Yes	Yes
rain	Yes	Yes
humidity	Yes	Yes
Fixed-effects		
Municipality by Month	Yes	Yes
Year by Month	Yes	Yes
Fit statistics		
Observations	6,243,812	6,134,897
R^2	0.73588	0.64245
Within R^2	5.15×10^{-5}	2.93×10^{-5}

Note: Table reports OLS estimates. The dependent variable is mortality rate. Clustered (Municipality) standard-errors in parentheses. Regressions are weighted by population. *p<0.1; **p<0.05; ***p<0.01.

Table 12: Number of deaths of people aged 75+ due to days with a maximum temperature > 35°C using coefficients for the period 2004 to 2019

Time Period	Number of deaths	Evolution
Reference period (1976-2005)	156	
Near horizon (2021-2050)	516	+231%
Medium horizon (2041-2070)	772	+50%

Model : CNRM-CERFACS-CNRM-CM5 / CNRM-ALADIN63
(Météo-France / Centre National de Recherches Météorologiques) via DRIAS

Table 13: Number of deaths of people aged over 75 related to each temperature bins based on coefficients for the period 1980-2003 and for the period 2004-2019

Temperature bins	deaths/year (coef 1980-2003)	deaths/year (coef 2004-2019)	difference
<-20 to -15 °C	0.287	0.168	-0.1
-15 to -10 °C	9	5	-4
-10 to -5 °C	67	101	+34
-5 to 0 °C	1,557	1,030	-527
0 to 5 °C	8,272	4,794	-3478
5 to 10 °C	7,788	4,560	-3228
10 to 15 °C	7,606	2,452	-5154
15 to 20 °C	0	0	0
20 to 25 °C	5,794	1,324	-4470
25 to 28 °C	571	733	+162
28 to 30 °C	803	326	-477
> 30 °C	700	106	-594
Total	33,167	15,432	-17,735

Note: This table reports the estimated annual number of deaths over 75 years old associated with each temperature bins based on the previously estimated coefficients of temperatures on mortality and the frequency of days in each bins based on the period 2015-2019 in each municipality and also data on the population by age in each municipality.

Figures

Figure 1: Population Weighted Average number of days per year in each temperature bins

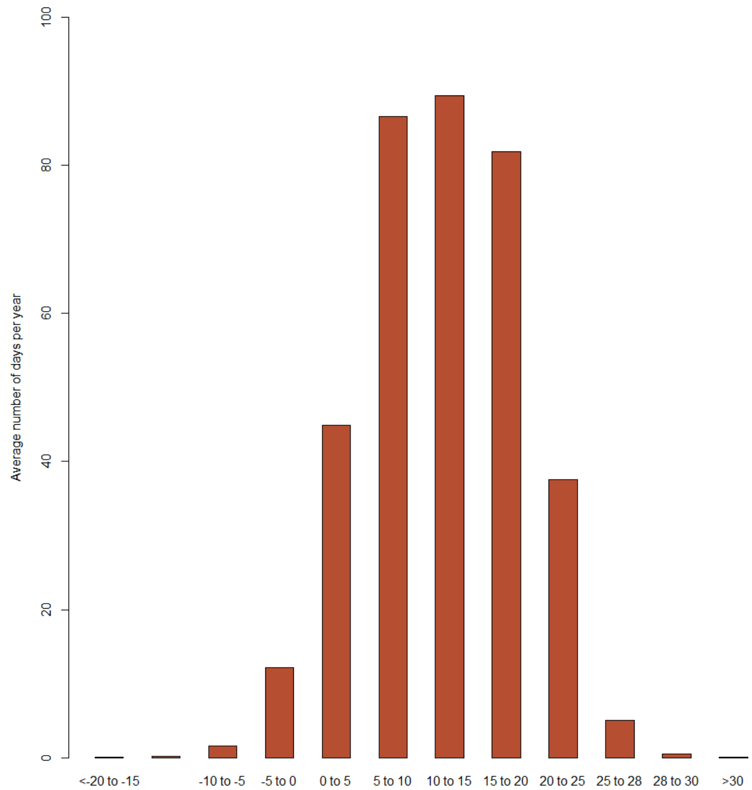
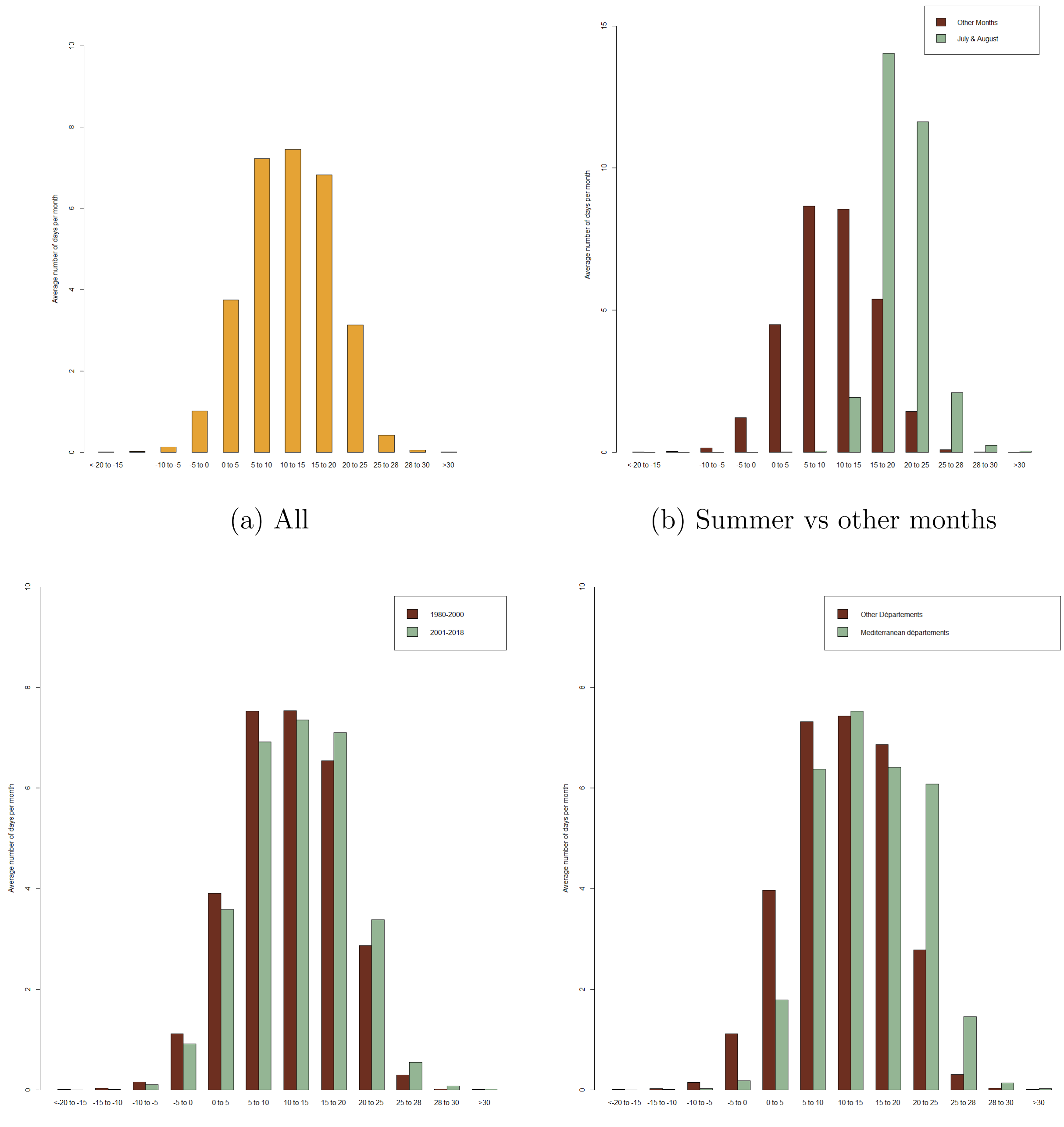


Figure 2: Population Weighted Average number of days per month in each temperature bins



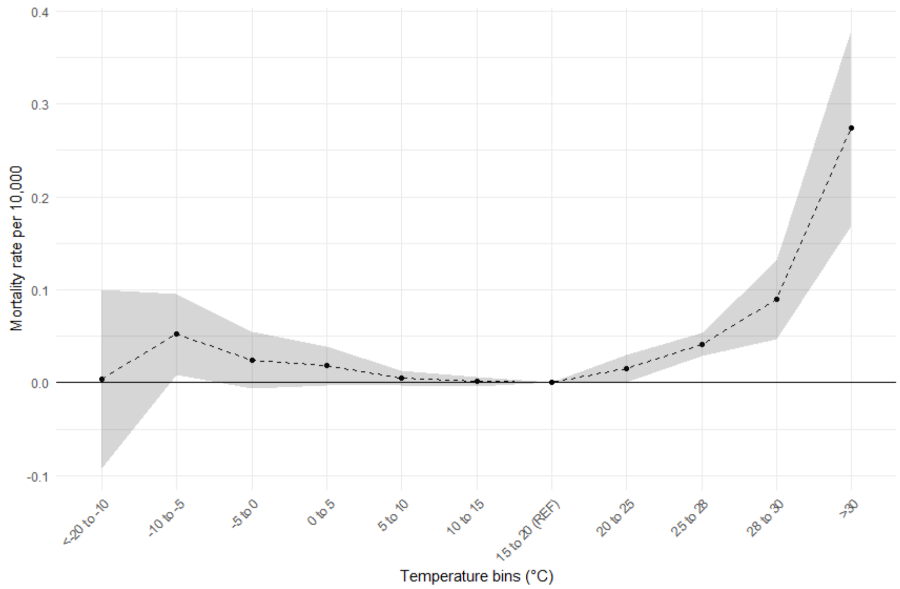
(a) All

(b) Summer vs other months

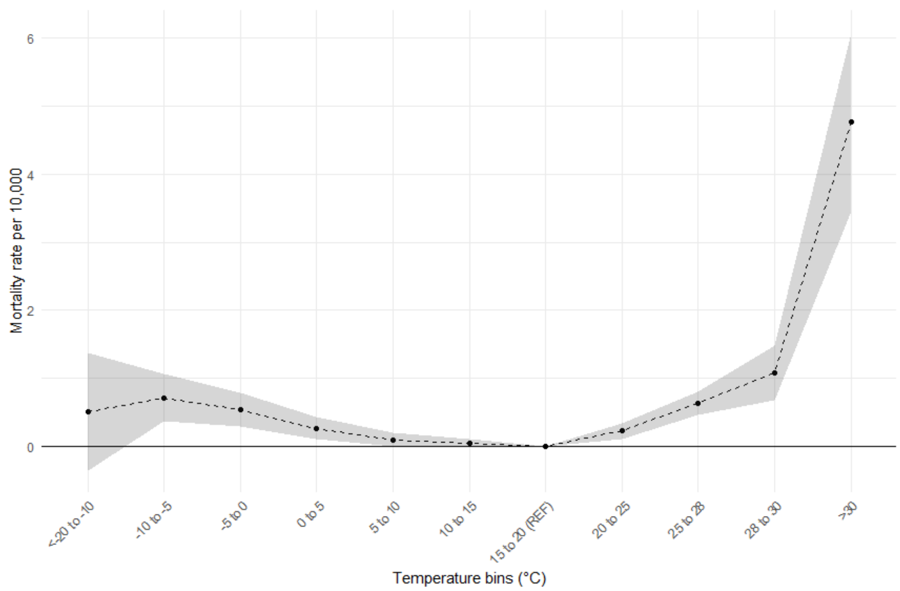
(c) 1980-2000 vs 2001-2018

(d) Mediterranean

Figure 3: Coefficients of temperature on mortality rate

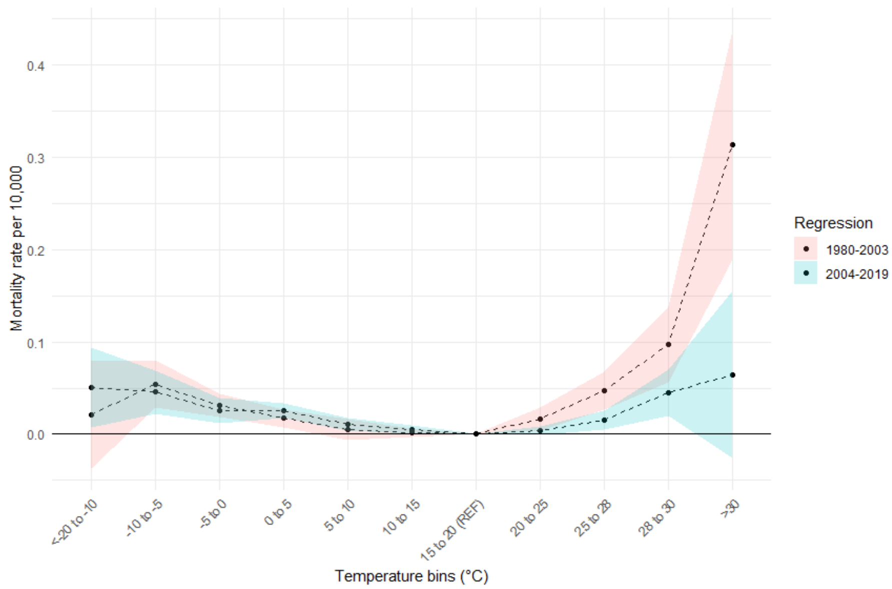


(a) All

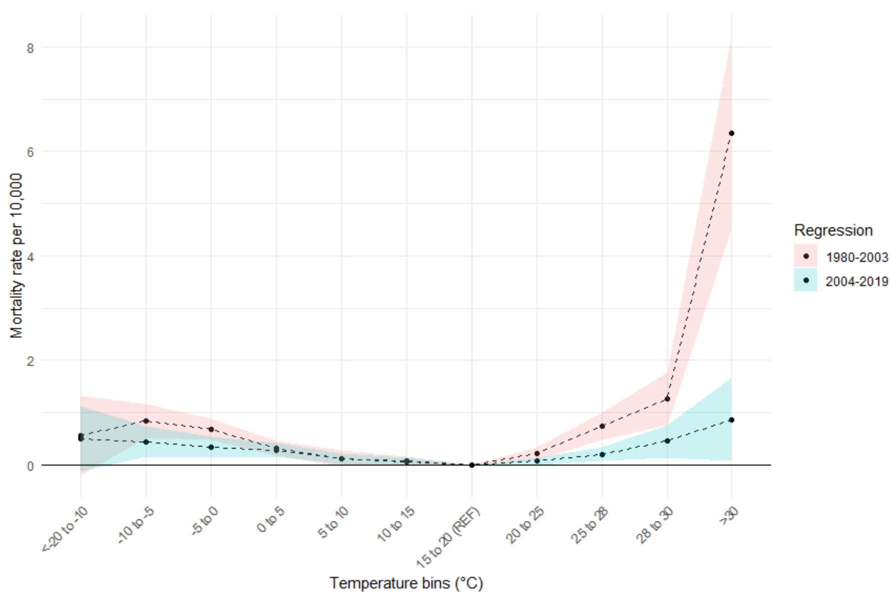


(b) Over 80 years old

Figure 4: Coefficient of temperature on mortality rate on period 1980-2003 vs 2004-2019



(a) All



(b) Over 80 years old

Figure 5: Coefficient of temperature on mortality rate 80+ by population density

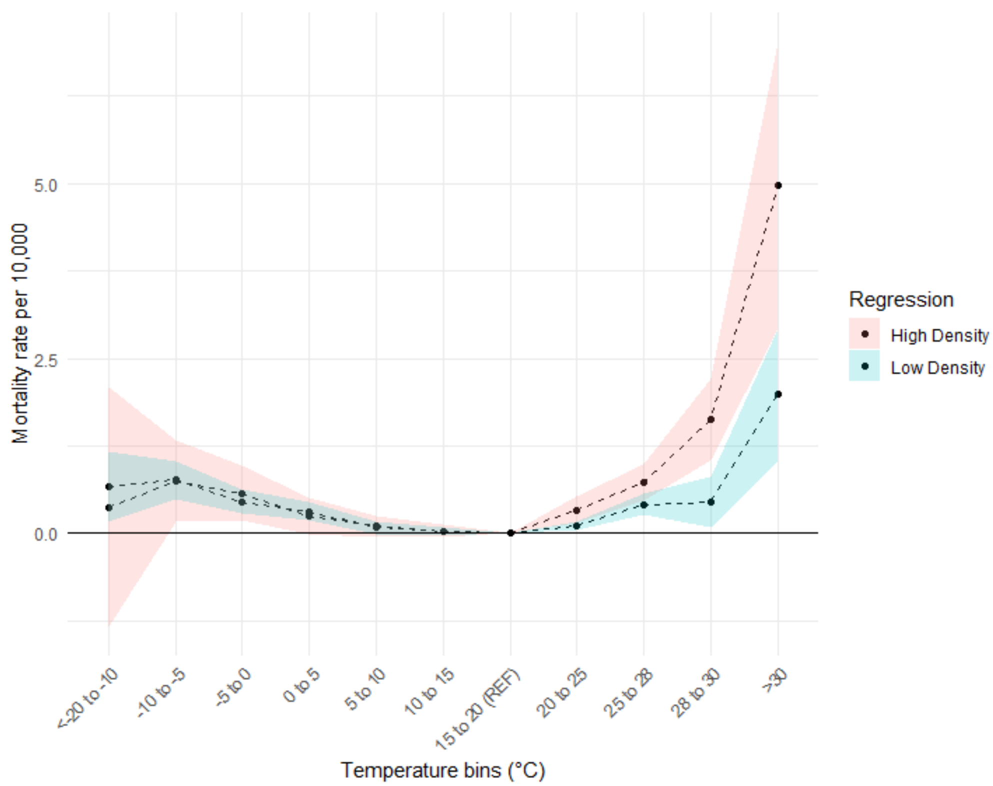
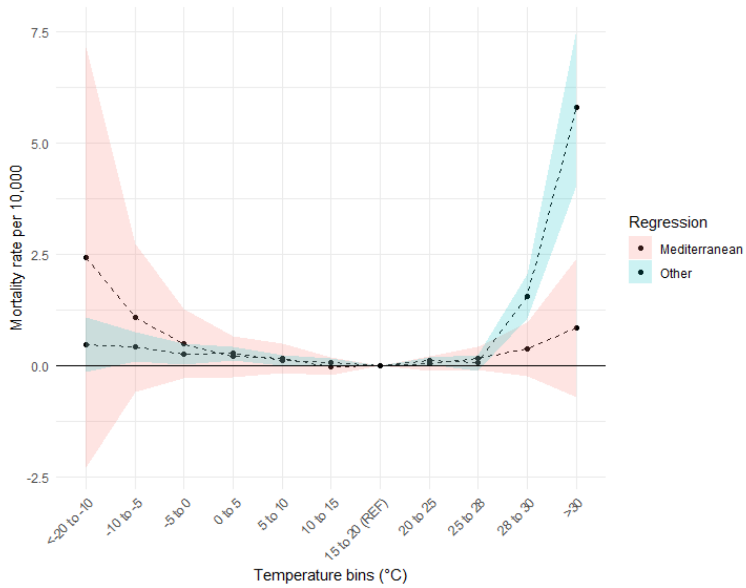
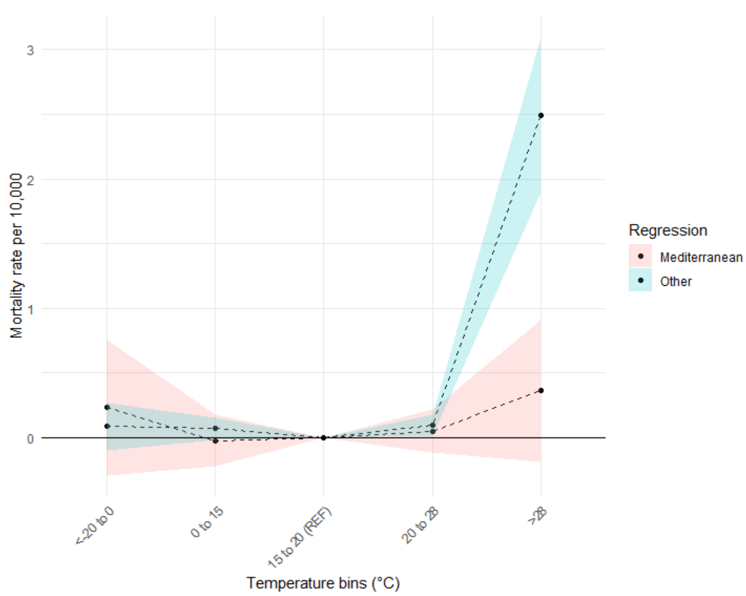


Figure 6: Coefficient of temperature on mortality rate of people over 80 years old in Mediterranean and non-Mediterranean municipalities



(a) All bins



(b) Fewer bins

Figure 7: Air conditionning equipment rate by decile of income

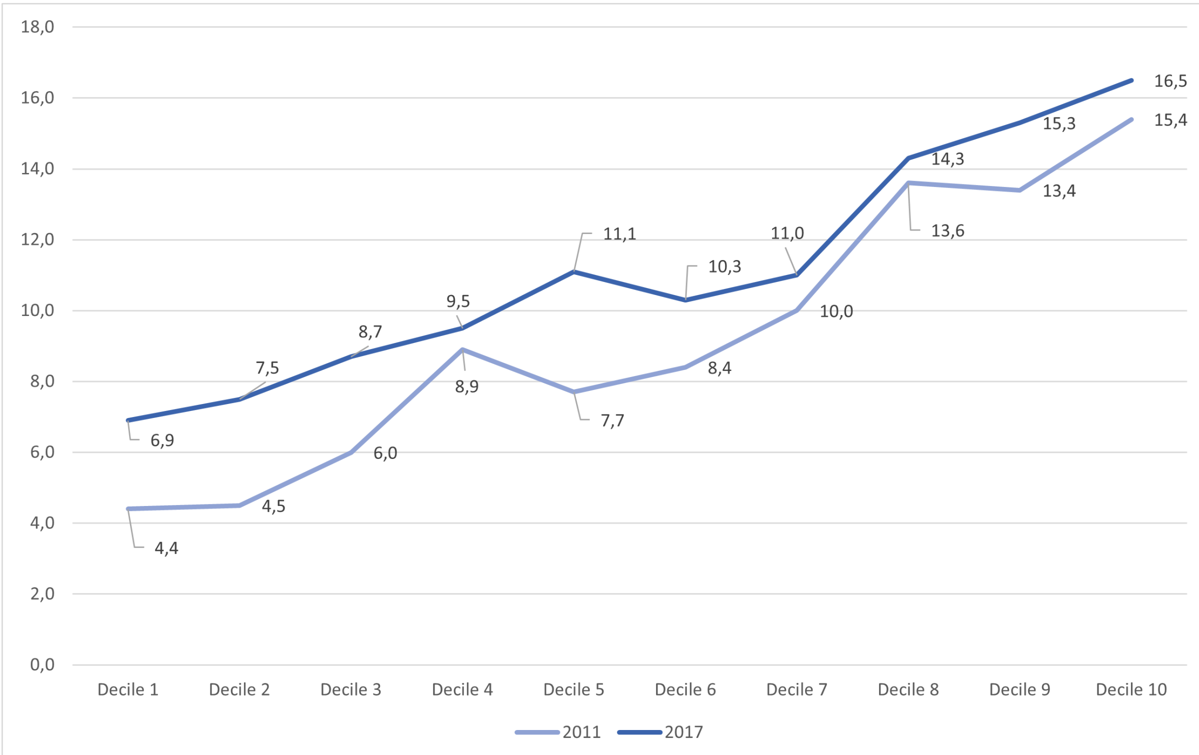


Figure 8: Air conditionning equipment rate by region

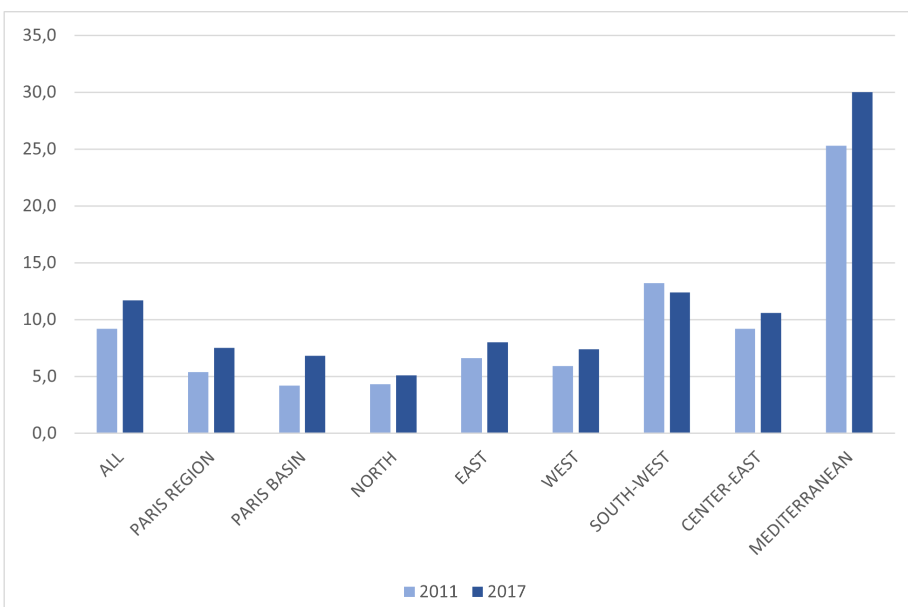


Figure 9: Air conditioning equipment rate 2021 (Lite data)

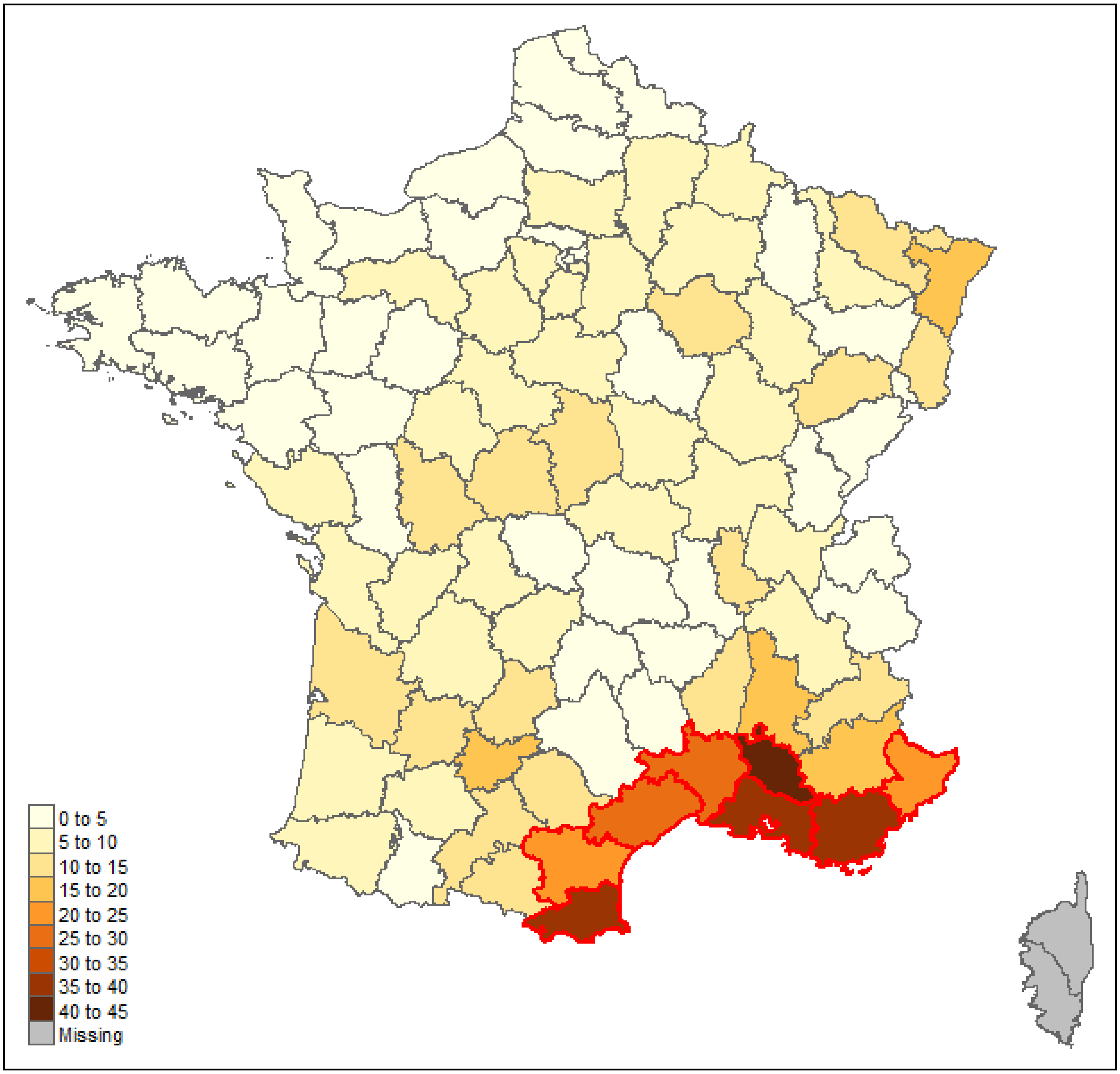


Figure 10: Average annual number of days above 25°C over the 2015-2019 period

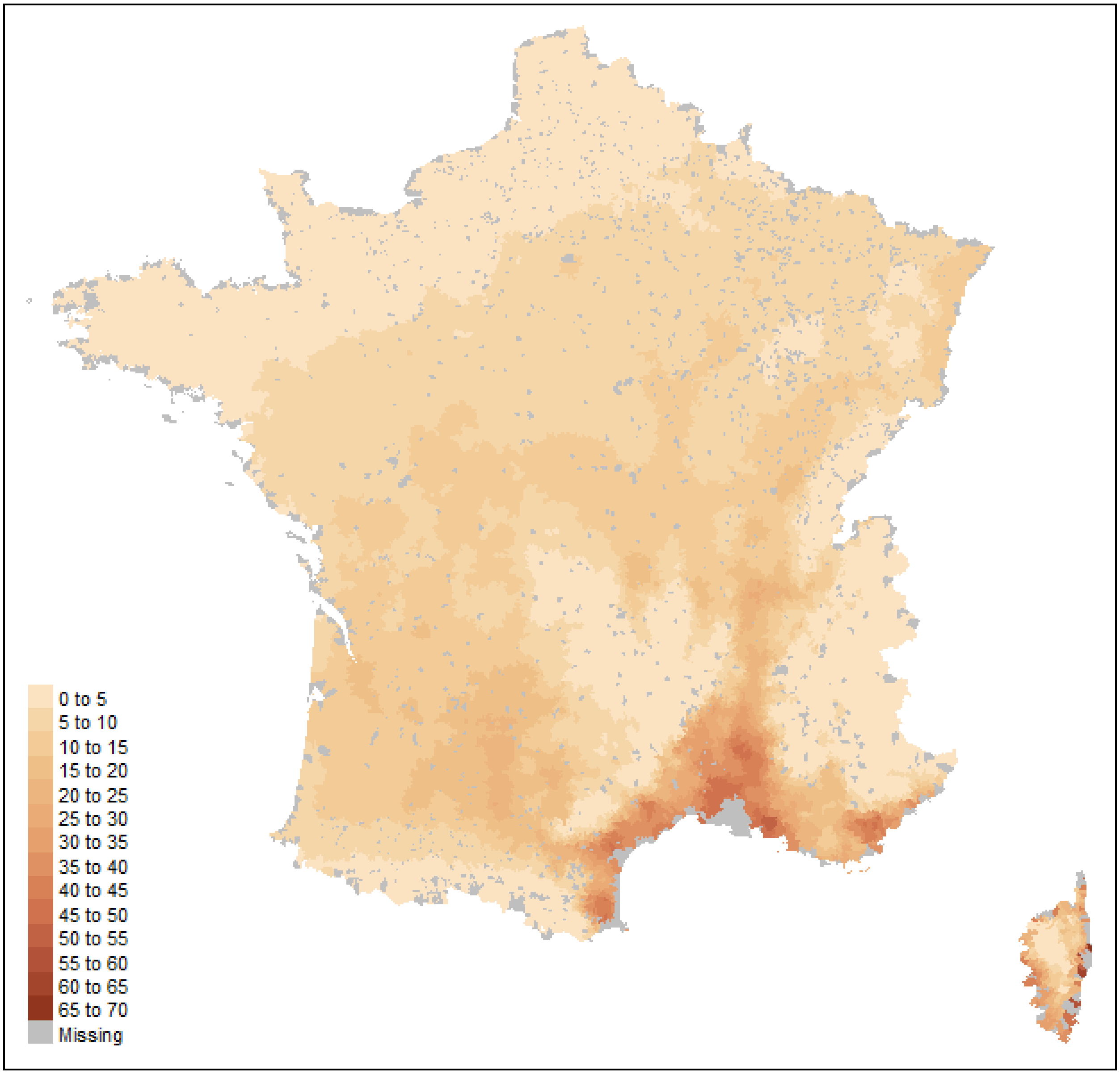


Figure 11: Annual number of days with a maximum temperature above 35°C over the reference period (1976-2005)

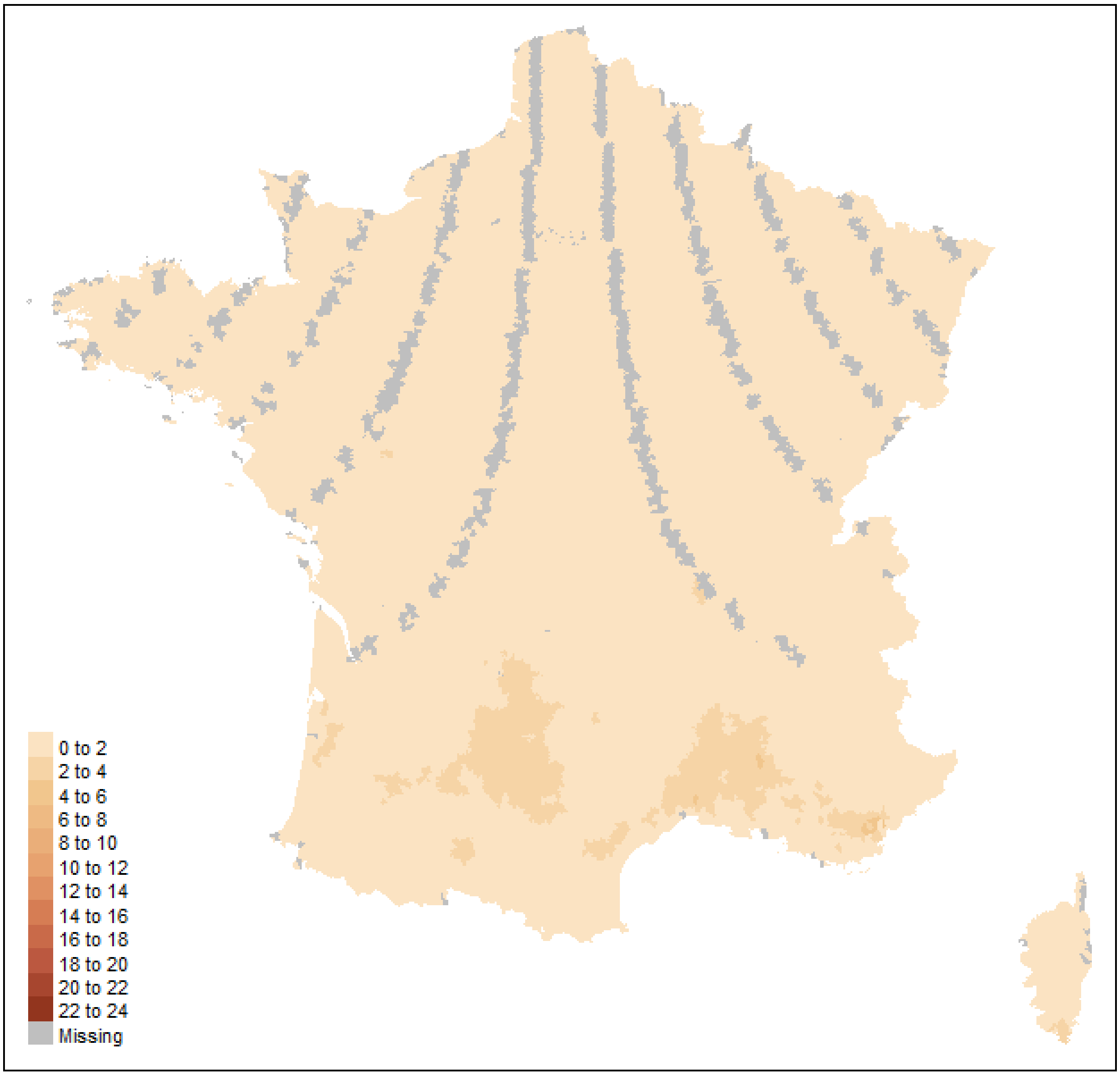


Figure 12: Annual number of days with a maximum temperature above 35°C over the near horizon (2021-2050)

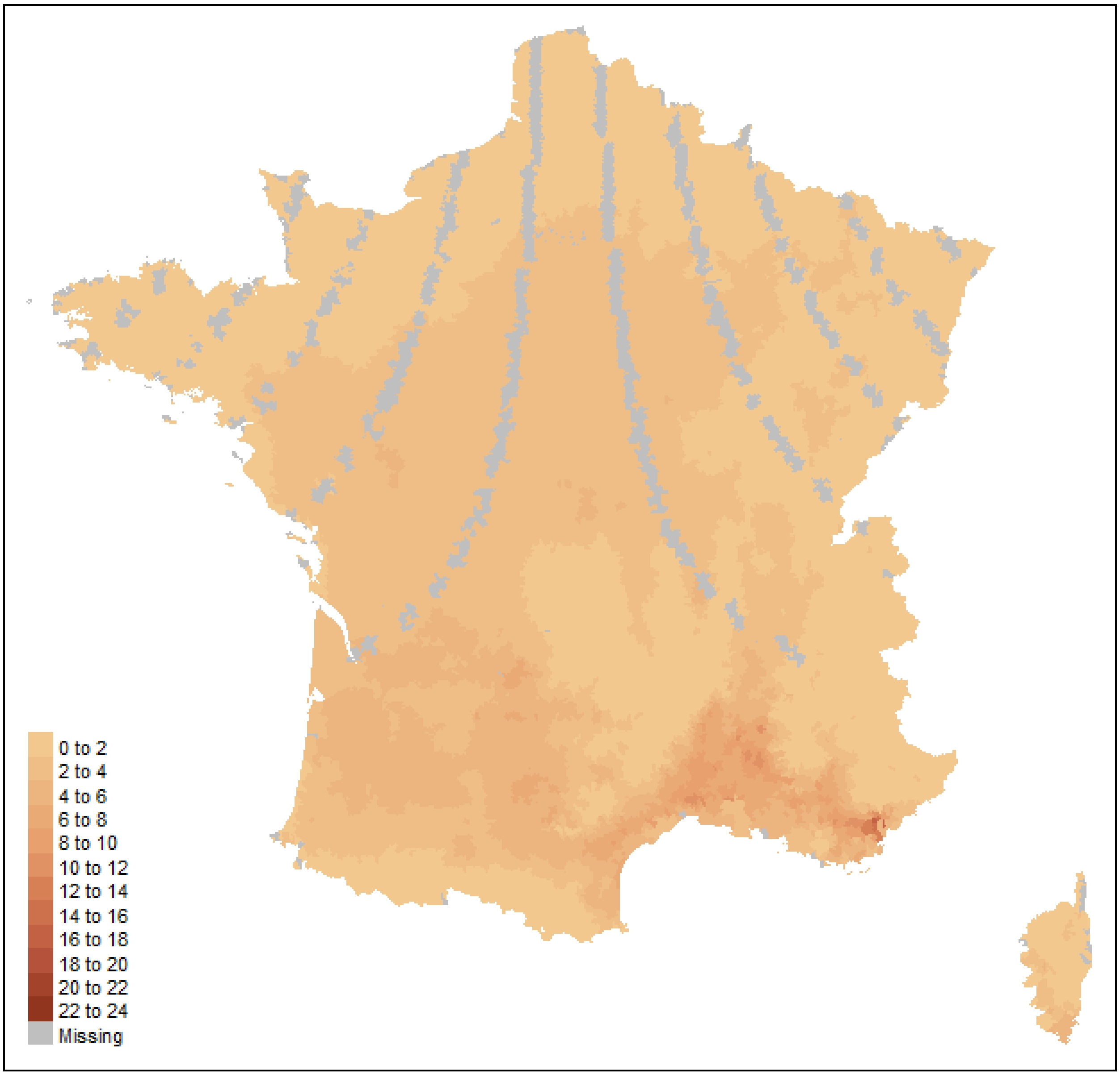


Figure 13: Annual number of days with a maximum temperature above 35°C over the medium horizon (2041-2070)

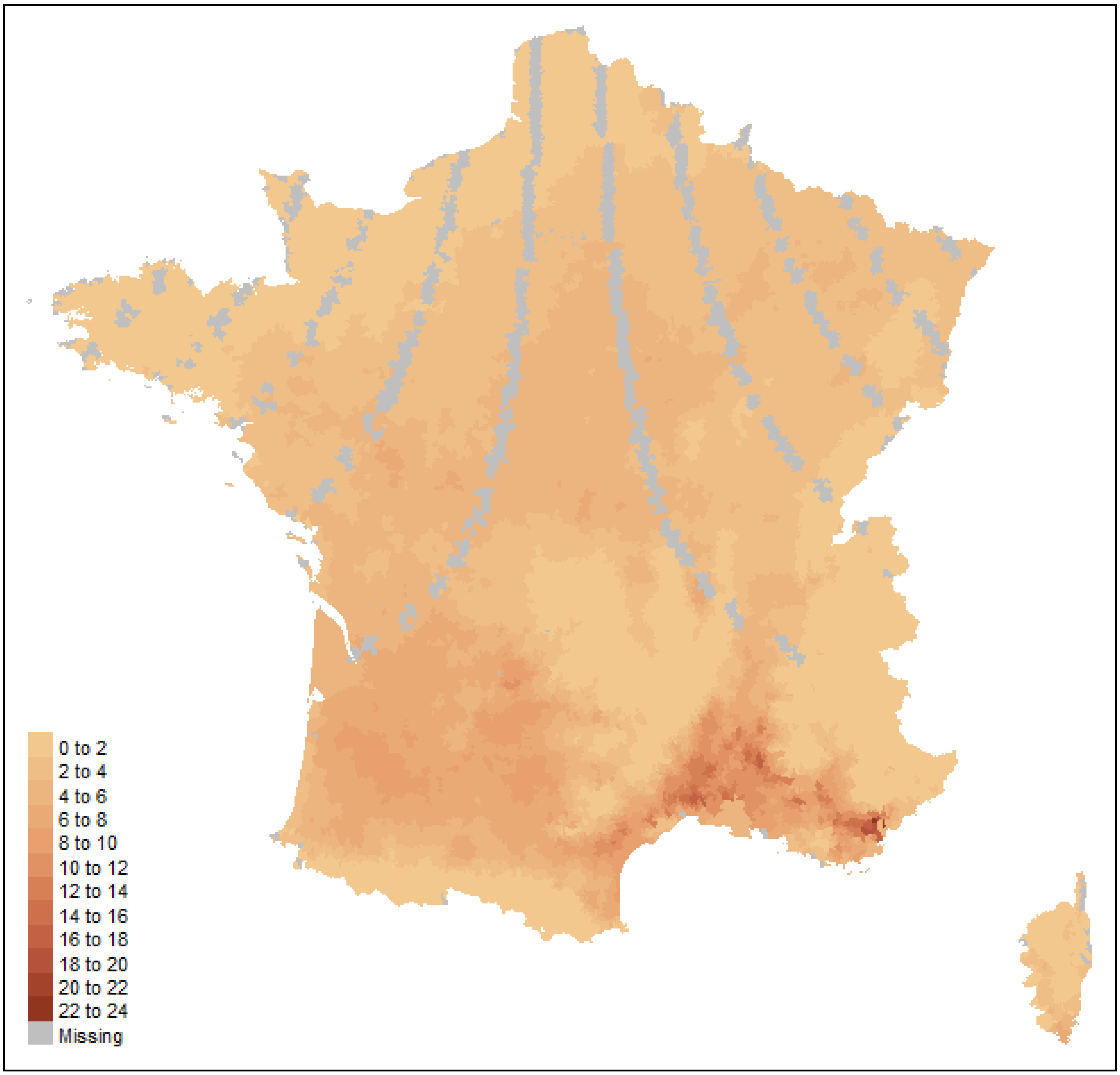


Figure 14: Coefficients of maximum temperature on mortality

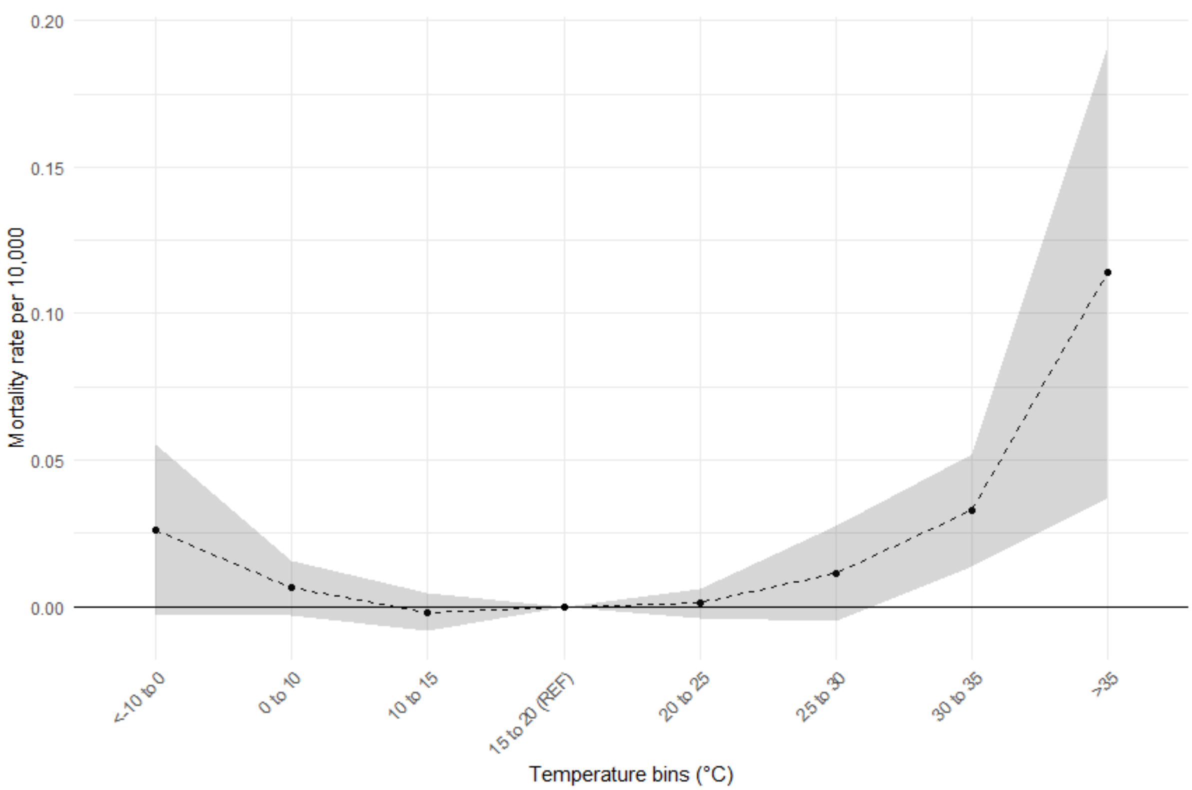
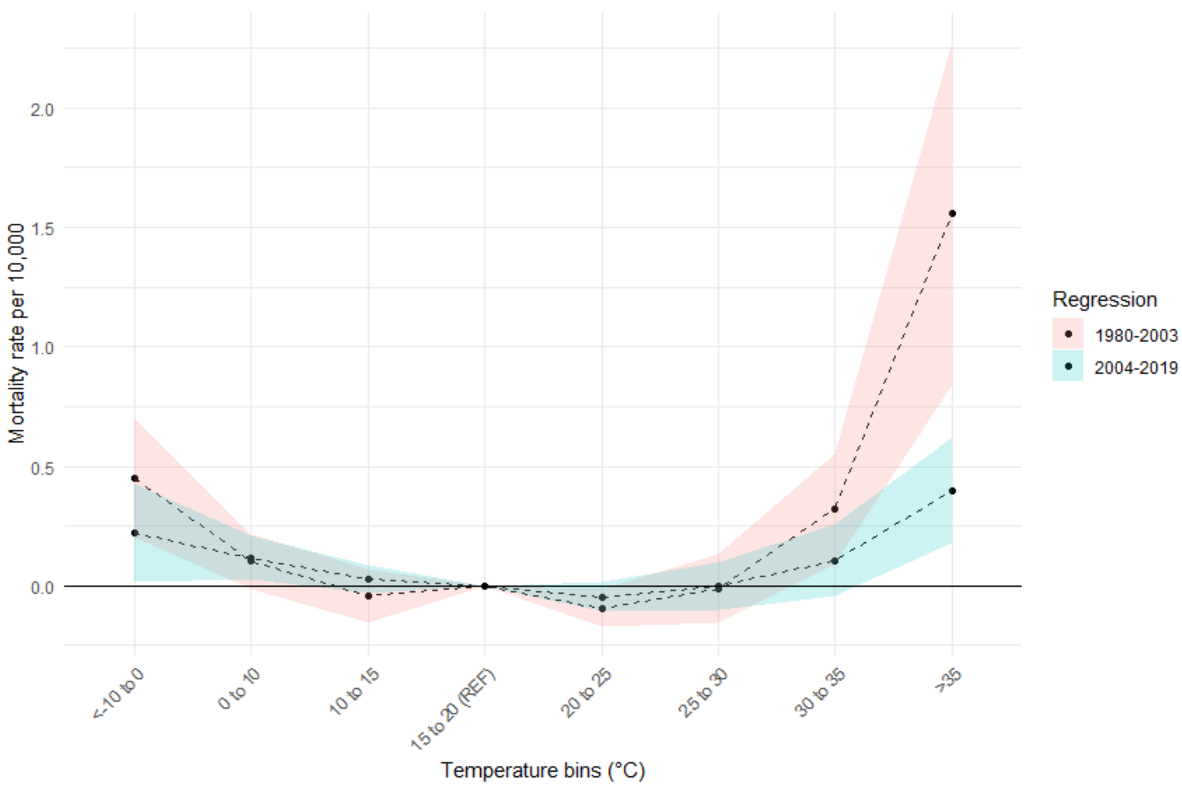


Figure 15: Coefficients of maximum temperature on mortality 80 plus



A Appendix

A Mergers and splits of municipalities

Over the period studied, several municipalities merged with each other. In most cases, this is a simple merger, so I kept the post-merger municipalities in the database and excluded the formerly autonomous municipalities. In the pre-merger period, I aggregate the data of the municipalities forming the future merger by averaging them. However, mergers and splits are sometimes more complex. For example, a municipality may merge with another municipality and split again.

We therefore use the INSEE data file, which lists all the events that have occurred in the municipalities since 1943[34]. The MOD variable in the database describes all the possible events in the municipality and the coding of the events[35].

The MOD codes correspond to the following operations (a municipality can have several operations and therefore several MOD codes):

1) simple merger: 31, 32, 33 2) split: 30, 20 3) merger then split: 21 4) codes that can be ignored: 10, 35, 41, 50, 70, 34

Although most cases are simple mergers, several events can occur at the same time, such as a merger followed by a split. Details of the most common procedures are given here:

1) In the case of a municipality that merges to create a new municipality and then splits again: we keep the municipality after the merger. The data for the pre-merger municipalities is aggregated on average, as is the data for the post-merger municipalities. This makes it possible to keep the data for a municipality over the entire period. 2) In the case of a simple split, we keep the pre-split commune and aggregate the post-split data on average. 3) In the case of a merger then a second merger, we keep the last merged municipality, then we establish the same procedure as with a simple merger with the former municipalities. 4) For double splits, we follow the same procedure in the opposite direction.

Operations involving delegated and associated municipalities can be ignored. These municipalities are the result of a merger-association between several municipalities and no longer have the status of a territorial authority, but retain certain administrative characteristics that are not linked to the geographical boundary. There are special cases not detailed here which only concern a very small number of municipalities and which are detailed in the code R (soon publicly available).

[34]open access : https://www.insee.fr/fr/information/6051727
[35]https://www.insee.fr/fr/information/5057793

B Evolution of the effect of temperature

Table A.1: Effect of temperature on mortality over time

Dependent Variables:	Mortality rate (total)	Mortality rate 80+	Mortality rate 75-79	Mortality rate 70-74	Mortality rate men	Mortality rate women
Model:	(1)	(2)	(3)	(4)	(5)	(6)
Variables						
< -20 to -15 °C	6.905	111.2	32.55	96.82	5.196	8.613
	(8.631)	(155.9)	(79.09)	(59.37)	(12.56)	(9.138)
-15 to -10 °C	-0.5507	-37.67	32.42	27.54*	-1.228	0.1259
	(2.278)	(38.66)	(24.07)	(14.53)	(2.898)	(2.655)
-10 to -5 °C	-3.575***	-1.635	4.720	11.30*	-2.846***	-4.298***
	(0.8590)	(13.42)	(8.302)	(5.773)	(0.9696)	(1.001)
-5 to 0 °C	1.286***	42.22***	18.71***	10.17***	1.041*	1.539***
	(0.4619)	(6.148)	(3.246)	(2.171)	(0.5467)	(0.4433)
0 to 5 °C	-1.384***	-19.74***	6.342***	-1.057	-1.342***	-1.436***
	(0.3531)	(3.849)	(1.900)	(1.398)	(0.3781)	(0.3523)
5 to 10 °C	-1.018	3.700	-3.104	-1.835	-1.178	-0.8518
	(0.6914)	(4.987)	(2.052)	(1.284)	(0.7469)	(0.6471)
10 to 15 °C	0.1979	4.978	-0.0008	-1.673	0.0855	0.3110
	(0.5649)	(3.868)	(1.755)	(1.228)	(0.6455)	(0.5035)
20 to 25 °C	0.3728	-1.825	-11.47***	-7.172***	0.0616	0.6705
	(1.025)	(7.324)	(3.388)	(2.244)	(1.175)	(0.9048)
25 to 28 °C	5.338***	94.31***	-15.48***	11.33***	4.739***	5.902***
	(1.588)	(9.046)	(5.593)	(3.243)	(1.835)	(1.423)
28 to 30 °C	-0.9903	7.388	34.13*	-42.46***	-3.019	0.9377
	(4.717)	(45.46)	(20.26)	(12.10)	(5.029)	(4.759)
> 30 °C	33.03***	552.9***	146.2***	-19.83	20.24**	44.71***
	(8.376)	(130.2)	(49.53)	(36.80)	(9.419)	(9.095)
year	0.0171***	-0.6115***	-0.5629***	-0.3918***	0.0093**	0.0247***
	(0.0037)	(0.0431)	(0.0235)	(0.0163)	(0.0044)	(0.0034)
< -20 to -15 °C × year	-0.0034	-0.0554	-0.0162	-0.0488	-0.0026	-0.0043
	(0.0043)	(0.0781)	(0.0396)	(0.0297)	(0.0063)	(0.0046)
-15 to -10 °C × year	0.0003	0.0194	-0.0159	-0.0136*	0.0006	-3.98×10^{-5}
	(0.0011)	(0.0194)	(0.0120)	(0.0073)	(0.0015)	(0.0013)
-10 to -5 °C× year	0.0018***	0.0012	-0.0022	-0.0055*	0.0015***	0.0022***
	(0.0004)	(0.0067)	(0.0041)	(0.0029)	(0.0005)	(0.0005)
-5 to 0 °C × year	-0.0006***	-0.0209***	-0.0093***	-0.0051***	-0.0005*	-0.0008***
	(0.0002)	(0.0031)	(0.0016)	(0.0011)	(0.0003)	(0.0002)
0 to 5 °C × year	0.0007***	0.0100***	-0.0031***	0.0006	0.0007***	0.0007***
	(0.0002)	(0.0019)	(0.0009)	(0.0007)	(0.0002)	(0.0002)
5 to 10 °C × year	0.0005	-0.0017	0.0015	0.0010	0.0006	0.0004
	(0.0003)	(0.0025)	(0.0010)	(0.0006)	(0.0004)	(0.0003)
10 to 15 °C × year	-9.3×10^{-5}	-0.0024	-2.98×10^{-6}	0.0009	-3.72×10^{-5}	-0.0001
	(0.0003)	(0.0019)	(0.0009)	(0.0006)	(0.0003)	(0.0003)
20 to 25 °C × year	-0.0002	0.0010	0.0057***	0.0036***	-2.63×10^{-5}	-0.0003
	(0.0005)	(0.0037)	(0.0017)	(0.0011)	(0.0006)	(0.0005)
25 to 28 °C × year	-0.0026***	-0.0467***	0.0077***	-0.0056***	-0.0023**	-0.0029***
	(0.0008)	(0.0045)	(0.0028)	(0.0016)	(0.0009)	(0.0007)
28 to 30 °C × year	0.0006	-0.0028	-0.0165	0.0213***	0.0016	-0.0004
	(0.0024)	(0.0227)	(0.0101)	(0.0060)	(0.0025)	(0.0024)
> 30 °C × year	-0.0163***	-0.2721***	-0.0720***	0.0104	-0.0099**	-0.0220***
	(0.0042)	(0.0646)	(0.0246)	(0.0183)	(0.0047)	(0.0045)
Controls						
Wind	Yes	Yes	Yes	Yes	Yes	Yes
rain	Yes	Yes	Yes	Yes	Yes	Yes
humidity	Yes	Yes	Yes	Yes	Yes	Yes
Fixed-effects						
Municipality by Month	Yes	Yes	Yes	Yes	Yes	Yes
Month	Yes	Yes	Yes	Yes	Yes	Yes
Fit statistics						
Observations	15,641,050	14,765,824	14,685,286	14,832,998	15,640,669	15,639,831
R^2	0.63883	0.39800	0.29160	0.24409	0.55445	0.51488
Within R^2	0.00211	0.00454	0.00852	0.00665	0.00072	0.00225

Note: Table reports OLS estimates. The dependent variable is mortality rate. Clustered (Municipality) standard-errors in parentheses. Regressions are weighted by population. *p<0.1; **p<0.05; ***p<0.01.

C Region by year fixed effects

Table A.2: Effect of temperature on mortality with Region by year fixed effects

Dependent Variables:	Mortality rate (total)	Mortality rate 80+
Model:	(1)	(2)
Variables		
< -20 to -15 °C	0.0811*	1.301
	(0.0428)	(0.9959)
-15 to -10 °C	-0.0053	0.7695***
	(0.0109)	(0.2268)
-10 to -5 °C	0.0496***	0.7568***
	(0.0049)	(0.0804)
-5 to 0 °C	0.0219***	0.4624***
	(0.0019)	(0.0333)
0 to 5 °C	0.0160***	0.2270***
	(0.0016)	(0.0232)
5 to 10 °C	0.0140***	0.2082***
	(0.0011)	(0.0183)
10 to 15 °C	0.0131***	0.1667***
	(0.0010)	(0.0154)
20 to 25 °C	0.0001	0.0333*
	(0.0014)	(0.0171)
25 to 28 °C	0.0249***	0.3926***
	(0.0032)	(0.0402)
28 to 30 °C	0.1226***	1.713***
	(0.0101)	(0.1578)
> 30 °C	0.3753***	6.352***
	(0.0371)	(0.6185)
Controls		
Wind	Yes	Yes
rain	Yes	Yes
humidity	Yes	Yes
Fixed-effects		
Municipality-Month	Yes	Yes
Region (Département) -year	Yes	Yes
Fit statistics		
Observations	15,641,050	14,765,824
R^2	0.64178	0.40053
Within R^2	0.00041	0.00032

Note: Table reports OLS estimates. The dependent variable is mortality rate. Clustered (Municipality) standard-errors in parentheses. Regressions are weighted by population. *p<0.1; **p<0.05; ***p<0.01.

Table A.3: Effect of temperature on mortality by population density, Region by year fixed effects

Dependent Variables:	Mortality rate (total)	Mortality rate 80+
Model:	(1)	(2)
Variables		
< -20 to -15 °C	0.4356***	3.003
	(0.1325)	(2.552)
-15 to -10 °C	0.2411***	0.4924
	(0.0394)	(0.7019)
-10 to -5 °C	0.0702***	0.7324***
	(0.0178)	(0.2386)
-5 to 0 °C	0.0886***	0.1781
	(0.0098)	(0.1554)
0 to 5 °C	0.0809***	0.4549***
	(0.0092)	(0.1058)
5 to 10 °C	0.0505***	0.0561
	(0.0080)	(0.0886)
10 to 15 °C	0.0314***	0.0206
	(0.0046)	(0.0616)
20 to 25 °C	-0.0217***	-0.2139***
	(0.0046)	(0.0577)
25 to 28 °C	-0.0357	-0.1269
	(0.0251)	(0.2176)
28 to 30 °C	-0.0314	-1.364**
	(0.0513)	(0.6497)
> 30 °C	-0.2326*	-5.452**
	(0.1338)	(2.353)
log(density)	-3.189***	13.91***
	(0.3362)	(4.497)
< -20 to -15 °C × log(density)	-0.0769***	-0.3730
	(0.0293)	(0.6192)
-15 to -10 °C × log(density)	-0.0432***	0.0530
	(0.0079)	(0.1407)
-10 to -5 °C × log(density)	-0.0026	0.0037
	(0.0033)	(0.0430)
-5 to 0 °C × log(density)	-0.0108***	0.0466*
	(0.0016)	(0.0267)
0 to 5 °C × log(density)	-0.0105***	-0.0380**
	(0.0015)	(0.0174)
5 to 10 °C × log(density)	-0.0059***	0.0242*
	(0.0014)	(0.0146)
10 to 15 °C × log(density)	-0.0029***	0.0231**
	(0.0007)	(0.0100)
20 to 25 °C × log(density)	0.0035***	0.0394***
	(0.0008)	(0.0096)
25 to 28 °C × log(density)	0.0095**	0.0801**
	(0.0040)	(0.0359)
28 to 30 °C × log(density)	0.0251***	0.4974***
	(0.0090)	(0.1249)
> 30 °C × log(density)	0.0871***	1.696***
	(0.0238)	(0.4276)
Controls		
Wind	Yes	Yes
rain	Yes	Yes
humidity	Yes	Yes
Fixed-effects		
Municipality-Month	Yes	Yes
Region (Département) -year	Yes	Yes
Fit statistics		
Observations	15,641,050	14,765,824
R^2	0.64254	0.40063
Within R^2	0.00254	0.00048

Note: Table reports OLS estimates. The dependent variable is mortality rate. Clustered (Municipality) standard-errors in parentheses. Regressions are weighted by population. *p<0.1; **p<0.05; ***p<0.01.

Table A.4: Effect of temperature on mortality, temperature lag, Region by year fixed effects

Dependent Variables:	Mortality rate (total)	Mortality rate 80+
Model:	(1)	(2)
Variables		
< -20 to -15 °C	0.0906**	1.436
	(0.0453)	(1.045)
-15 to -10 °C	-0.0179	0.6421***
	(0.0118)	(0.2445)
-10 to -5 °C	0.0590***	0.8906***
	(0.0056)	(0.0845)
-5 to 0 °C	0.0208***	0.4567***
	(0.0021)	(0.0354)
0 to 5 °C	0.0148***	0.2168***
	(0.0017)	(0.0241)
5 to 10 °C	0.0132***	0.2032***
	(0.0012)	(0.0187)
10 to 15 °C	0.0119***	0.1486***
	(0.0010)	(0.0155)
20 to 25 °C	-0.0012	0.0180
	(0.0014)	(0.0172)
25 to 28 °C	0.0222***	0.3439***
	(0.0035)	(0.0403)
28 to 30 °C	0.1294***	1.776***
	(0.0104)	(0.1607)
> 30 °C	0.3855***	6.471***
	(0.0377)	(0.6183)
< -20°C_lag	0.1277	1.878
	(0.1838)	(3.769)
-20 to -15 °C_lag	-0.0143	-0.0155
	(0.0436)	(0.9518)
-15 to -10 °C_lag	-0.0626***	-0.1430
	(0.0106)	(0.2265)
-10 to -5 °C_lag	0.0060	0.2078***
	(0.0050)	(0.0777)
-5 to 0 °C_lag	0.0139***	0.3252***
	(0.0021)	(0.0326)
0 to 5 °C_lag	0.0085***	0.1196***
	(0.0017)	(0.0235)
5 to 10 °C_lag	-0.0013	-0.0050
	(0.0012)	(0.0176)
10 to 15 °C_lag	0.0067***	0.0810***
	(0.0015)	(0.0180)
20 to 25 °C_lag	-0.0016	-0.0233
	(0.0011)	(0.0163)
25 to 28 °C_lag	-0.0010	0.0086
	(0.0035)	(0.0350)
28 to 30 °C_lag	0.0040	-0.0835
	(0.0121)	(0.1349)
> 30 °C_lag	-0.0227	-0.2576
	(0.0170)	(0.2452)
Controls		
Wind	Yes	Yes
rain	Yes	Yes
humidity	Yes	Yes
LAG Wind	Yes	Yes
LAG rain	Yes	Yes
LAG humidity	Yes	Yes
Fixed-effects		
Municipality-Month	Yes	Yes
Region (Département) -year	Yes	Yes
Fit statistics		
Observations	15,304,358	14,448,225
R^2	0.64288	0.40033
Within R^2	0.00074	0.00052

Note: Table reports OLS estimates. The dependent variable is mortality rate. Clustered (Municipality) standard-errors in parentheses. Regressions are weighted by population. *p<0.1; **p<0.05; ***p<0.01.

Table A.5: Evolution of the Effect of temperature on mortality (1980-2003 vs 2004-2019), Region by year fixed effects

Dependent Variables:	Mortality rate (total)		Mortality rate 80+	
Model:	(1)	(2)	(3)	(4)
Variables				
< -20 to -15 °C	0.0713	0.1376	1.432	1.607
	(0.0442)	(0.1038)	(1.058)	(1.647)
-15 to -10 °C	-0.0142	0.0824***	0.2842	0.8364**
	(0.0120)	(0.0235)	(0.2550)	(0.3472)
-10 to -5 °C	0.0105	0.1082***	0.3432***	1.303***
	(0.0066)	(0.0073)	(0.1112)	(0.0966)
-5 to 0 °C	0.0077***	0.0526***	0.4058***	0.6924***
	(0.0028)	(0.0027)	(0.0492)	(0.0398)
0 to 5 °C	-0.0008	0.0312***	0.0936***	0.3889***
	(0.0020)	(0.0017)	(0.0333)	(0.0250)
5 to 10 °C	0.0044**	0.0166***	0.1422***	0.2001***
	(0.0018)	(0.0013)	(0.0288)	(0.0198)
10 to 15 °C	0.0110***	0.0083***	0.2057***	0.1073***
	(0.0012)	(0.0011)	(0.0213)	(0.0158)
20 to 25 °C	0.0013	0.0013	0.0561**	0.0106
	(0.0019)	(0.0013)	(0.0245)	(0.0169)
25 to 28 °C	0.0677***	0.0078***	1.007***	0.0469
	(0.0053)	(0.0028)	(0.0816)	(0.0334)
28 to 30 °C	0.1775***	0.0253***	2.705***	0.1808
	(0.0159)	(0.0095)	(0.2576)	(0.1217)
> 30 °C	0.4359***	0.0286	7.894***	0.2734
	(0.0540)	(0.0308)	(0.8774)	(0.3495)
Controls				
Wind	Yes	Yes	Yes	Yes
rain	Yes	Yes	Yes	Yes
humidity	Yes	Yes	Yes	Yes
Fixed-effects				
Municipality-Month	Yes	Yes	Yes	Yes
Region (Département) -year	Yes	Yes	Yes	Yes
Fit statistics				
Observations	9,397,238	6,243,812	8,804,965	5,960,859
R^2	0.64815	0.73588	0.39638	0.57348
Within R^2	0.00117	0.00038	0.00064	0.00034

Note: Table reports OLS estimates. The dependent variable is mortality rate. Clustered (Municipality) standard-errors in parentheses. Regressions are weighted by population. *p<0.1; **p<0.05; ***p<0.01.

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