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150 Years of temperature-related excess mortality in the Netherlands

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Abstract

Even in present-day high-income countries, there is a lot of evidence of a high degree of vulnerability of the population to both high and low outdoor temperatures. The magnitude of temperature-related mortality is strongly related to a wide variety of social, economic, and behavioural factors. To gain insight into the changing impact of cold and heat on mortality, we analyze Dutch individual death records in relation to daily temperature for the period 1855-2006 for one of the 11 Dutch provinces. Making use of negative binomial regression analysis, we study whether the effect of temperature varied by age, sex, and social class, and analyze the changes in the vulnerability to temperature fluctuations.

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1. Introduction

In temperate zones, such as Western Europe, epidemiological studies of seasonal fluctuations in the numbers of deaths mainly focus on excess mortality in the winter period. From the 1920s onwards, infectious diseases which were prevalent in the summer months were largely brought under control. Since then, winter cold has been the major seasonal factor affecting the death rate. A large number of studies have documented that, in the industrialised world, thousands of additional people die during each winter season depending on the coldness of the winters. Studies exploring the effects of winter cold on death rates have been published on England and Wales (Keatinge, Coleshaw, and Holmes 1989; McDowall 1981), the Netherlands (Kunst, Looman, and Mackenbach 1991), and Norway (Laake and Sverre 1996). In addition, some comparative studies on this question have been published (Analitis et al. 2008; Baccini et al. 2008; Healy 2003; Keatinge et al. 1997; McMichael et al. 2008).

Incidentally, sharp increases in the numbers of deaths were still observed in the 20th century during short periods of record high temperatures in particular regions, with the most notable example of this being the New York City heat wave of 1975. In August 2003, Western Europe experienced an unprecedentedly hot summer (probably the hottest in Europe since 1500, see Luterbacher et al. 2004) with deadly consequences for the population. In France in particular, this crisis had a major socio-political impact: the Minister of Health resigned, a number of high-ranking officials in the Ministry of Health were transferred, the organization of the French health care system came under attack, and vehement discussions took place on the responsibility of individual families toward older family members. For many European countries, detailed analyses of the excess mortality related to the August 2003 heat wave were published (for France, see, for example, Rey et al. 2007).

At around the same time, increased recognition of the process of climate change led to a growing interest in the potential effects of changes in climate on health. Haines et al. (2006) recently noted that “Climatologists now consider it very likely that human influence on the global climate has at least doubled the risk of a heat wave such as that experienced in 2003.” In this context as well, the effects on mortality of extremes of temperature became a key research challenge.

According to Haines et al. (2006), empirical observations of the relationship between short-term variations in weather and mortality over a long period of time are indispensable in determining whether changes in health might be expected following future changes in climate.

The relationship between weather and mortality is a research topic that is of interest not just to climatologists or epidemiologists, but also to historians. Knowledge of how societies coped with environmental shocks, such as extremely high temperatures, and of whether they were able to mitigate the effects of these changes on mortality, provides us with a valuable measure of societal development (Galloway 1994), including information about the deficiencies in the historical health care system (Carson et al. 2006). Studying the differences in vulnerability to environmental stress by social class, age, and sex gives us information about the conditions under which these groups lived, and about the ways in which these conditions changed over time (Bengtsson 2004).

The number of studies in which the relationship between weather variations and mortality is tracked over a long period of time is rather limited. Contemporary epidemiological studies shed little light on mortality increases in the past that resulted from hot summers or cold winters. They rarely cover a period long enough to encompass major economic, demographic, or epidemiological transitions (Carson et al. 2006). Historical studies of the relationship between weather and mortality are, as a rule, based on rather crude weather and mortality indicators. Mortality is mostly available only for the population as a whole, without distinctions by sex or age, and studies normally make use of routinely published statistical data on the numbers of deaths per month (see, for example, McDowall 1981). In a series of articles, Galloway (1988, 1994) studied the secular changes in the relationship between short-term fluctuations in weather and mortality, making use of data stretching over the period 1670 to 1909. The temperature data that he used were monthly averages, which were converted into seasonal averages, whereas the mortality data were on an annual basis (for a comparable approach of the short-term fluctuations in mortality in London during the period 1675-1825, see Landers 1986). Although these crude weather and mortality measures permit a continuous analysis over a long time period, they have major drawbacks. Seasonal measures are affected not only by the number of deaths caused by hot weather in the summer, but also by the numbers caused by cold weather in winter (Keatinge and Donaldson 2004). Changes in seasonal mortality are therefore difficult to interpret. More refined data, such as daily death counts, are needed to allow us to discern patterns of heat- or cold-related mortality. Cardiovascular heat deaths, for example, appear to occur at very short lags (0-1 day), and may in part be due to short-term displacement; it is therefore likely that an effect of heat-related mortality is attenuated even in a weekly-aggregated analysis (Carson et al. 2006). A further problem is that existing studies rarely make it possible to *compare* the effects of winter and summer periods.

Information at the national level on the numbers of deaths by date of death, age, and sex, which in recent decades has become available in many European countries, usually does not go further back in time than the 1970s. Historians who wished to study the relationship between weather conditions and mortality therefore rarely had the opportunity to use detailed information on days of death for a sufficiently large number of deaths. These records were collected only for small communities and restricted time periods. However, in recent years historical databases with this kind of information have become available for a number of countries. In this paper, we use data relating to one of the 11 provinces of the Netherlands, stretching over a period of 150 years. The data cover the period during which the Netherlands underwent a transition from a mortality regime characterized by high annual fluctuations in mortality due to the dominance of infectious diseases (1800-1875), to a regime in which infectious diseases disappeared and degenerative diseases became the most important cause of death. During this transition, the seasonal profile of mortality also changed as a consequence of the decrease in gastro-intestinal infections, particularly among infants, which in the past made up such a large part of the total number of deaths. The period we have chosen to study is also interesting because it was characterized by strong socioeconomic progress, which might have caused a reduction in the vulnerability of the population to external circumstances: national income grew rapidly after 1860, housing conditions improved, clothing became better, and food and fuel became widely available. Another advantage of our database is that it allows us to identify groups of people who were more vulnerable to hot or cold weather than others; we are able to study the effect of weather conditions according to age, sex, and, for a limited period, social class.

Of course our dataset also has some drawbacks. Extreme heat and extreme cold are scarce in the Netherlands, and even more so in the region that we have chosen to study: maximum temperatures in the Netherlands sporadically exceed 27° C, minimum temperatures are rarely below -10° C. As a consequence, the seasonal variation in mortality in the Netherlands is small by international standards (Healy 2003; Keatinge et al. 1997; Keatinge et al. 2000; McKee 1989). A further problem is that we do not have information on season-related variables, such as air pollution and influenza, which might have played a role in (changes in) winter and summer excess mortality.

2. Weather-related mortality

2.1 Mechanisms

In a large number of studies, overviews have been given of the factors that in contemporary societies account for an increase in mortality due to cold or heat. In discussing these factors we paraphrase the outline given by Keatinge and Donaldson (2004:1094-1095).

The authors distinguish two groups of factors that are responsible for cold-related death: coronary and cerebral thrombosis and respiratory diseases, with each group accounting for about half of the cold–related deaths. Few of the excess deaths in winter are simply due to the body cooling until vital organs, such as the heart, cease to function.

Cold stress causes an increase in arterial thrombosis because the blood becomes more concentrated, and so more liable to clot, during exposure to cold. The sequence of events is as follows. The body's first adjustment to cold stress is to shut down blood flow to the skin to conserve body heat, thus producing an excess of blood in central parts of the body. To correct this imbalance, salt and water are moved out from the blood into tissue spaces and eventually secreted. This leaves behind increased levels of red cells, white cells, platelets, and fibrinogen, and causes increased viscosity of the blood. All these changes promote clotting. The effect of these increases in thrombogenic factors in blood on mortality is stronger among the elderly. This is partly because baseline fibrinogen levels are much higher in the elderly, and partly because young people are protected from inter-arterial thrombosis by the fact that their arteries have a healthy endothelial lining, whereas the inner surfaces of the arteries of the elderly are commonly affected by atheroma, and are therefore much more prone to thrombosis. The increase in respiratory deaths can be attributed in part to the fact that respiratory infections spread more readily in cold weather. People crowd together in poorly ventilated spaces when it is cold. In addition, the breathing of cold air stimulates coughing and running of the nose, and this helps to spread respiratory viruses and bacteria. Cold stress also tends to suppress immune responses to infections. This train of events leading to respiratory deaths in winter often starts with a cold or a minor infection of the upper airways, which spread to the bronchi and the lungs, with secondary infections following, leading to pneumonia.

Heat-related mortality in temperate regions is rarely due to hyperthermia, or the overheating of the body until the body proteins are denatured. In present-day populations, coronary and cerebral thromboses account for many heat-related deaths. These thromboses result from hemoconcentration, caused by the loss of salt and water in sweat. Other heat-related deaths result from strain on failing hearts unable to provide the additional blood flow to the skin needed to expel heat from the body.

The precise effects of extreme heat or cold depend not on temperature alone,[5] but also on specific conditions in which the temperature decline or rise took place, and on other climatic conditions.

First, the effects of cold and heat may consist of a more or less *instantaneous effect, as well as a more delayed effect*. Falls in temperature in winter are closely followed by increased mortality, with characteristic periods of time for different causes of death. Other effects of winter on behaviour (for example, hours spent indoors), on

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[5] There is debate concerning the comparative impact of minimum, maximum, and average temperatures on mortality as well (Kalkstein and Davis 1989).

food intake (for example, fruit), and on the physiological and psychological condition (such as depression) peak some time after the lowest temperature values have been reached. Some slowly working mechanisms, such as respiratory infections, also play a role in high winter mortality. For periods of heat as well, it is possible to distinguish between immediate effects (such as acute myocardial infection) and the impact over time. The main effects of heat are usually visible on the current day, or may last another day or two (Pattenden, Nikiforov, and Armstrong 2003). Some studies suggest there are longer lags in winter than in summer.

Second, *the length of the period* of heat and cold might be a factor determining the effect on mortality. For heat and for cold, it might be assumed that the effect on mortality is higher the longer the period in which the temperature is extreme (Huynen et al. 2001). A limited number of studies on this issue have found that both the intensity and the duration of heat waves are related to excess mortality (Rey et al. 2007).

Third, *compensatory effects on mortality* might be registered when longer time periods are studied. The number of deaths caused by heat during heat waves is often assumed to be compensated for by a fall in the numbers of deaths in subsequent weeks. The suggestion is that heat mainly has an effect on people whose health is already impaired, and who would have died within a short time anyway. This compensating effect is known as a ‘harvesting’ effect. This effect implies that only a portion of the excess mortality due to extreme heat is avoidable. Studies report conflicting results. For example, a recent study (Huynen et al. 2001) using daily deaths and temperature for the Netherlands (for the period 1984-1997) did not find such a harvesting effect during heat waves and cold spells. Indeed, much less is known about cold-induced than about heat-induced mortality displacement (Kunst, Looman, and Mackenbach 1993).

Fourth, the effects of heat and cold might also be dependent on *the sudden occurrence of a change in temperature*. Rapid changes in the weather, usually associated with periods of cooling, appear to increase mortality (Galloway 1994). A recent study on daily mortality variation in 12 US cities revealed that the risk of death on hot days rose with increasing variation in summertime temperatures (Braga, Zanobetti, and Schwartz 2001). The effects of heat and cold depend on whether populations have had the chance to adapt themselves to extreme weather conditions. The effects of heat waves, for example, are more dangerous at the start of the summer, when vulnerable people have not had time enough to acclimatize themselves to the high temperatures (Ballester, Michelozzi, and Iniguez 2003). Excess mortality during a second heat wave in a year is low compared to excess mortality during the first (Kalkstein and Davis 1989), and heat waves occurring late in the summer have less severe effects (Rooney et al. 1998).

Fifth, the effects of outdoor air temperature might be *modified by other weather conditions*. The effect on the human body, and on the mortality level, of being exposed to high or low ambient temperatures is partly dependent on other weather conditions. According to physiological laws, the effects of heat on the thermal balance of the body are increased by high humidity, a factor which reduces the cooling effect of sweating, and are mitigated by strong air flow, a factor which favours the cooling of the body. The effects of cold are, on the other hand, increased by strong air flow. Various measures have been proposed to include all environmental factors that enter into the human heat balance into one single heat index, but they call for very sophisticated measurements and calculations, and are highly complex (Gill et al. 1988). In addition, the effects found in recent studies are contradictory. Mean wind speed did not have an effect on mortality in a recent English study, but wind direction was found to have a slight effect. No interactions between wind direction and cold temperature were observed. Estimates for cold and heat also remained unchanged when relative humidity was controlled for (Hajat, Kovats, and Lachowycz 2007). A study of daily variations in mortality in relation to temperature, and two wind-chill indices for the Netherlands (1979-87), showed that hazardous weather situations could be identified almost as accurately by temperature as by an index that also included wind-chill (Kunst, Groenhof, and Mackenbach 1994).

Finally, the effect of high and low temperatures also depends on *the climatological situation of the region* studied. Studies of populations living in widely different climates show that they have adjusted to their own climate remarkable effectively over time. This applies to cold as well as to hot regions. Heat-related mortality occurs at higher temperatures in hotter regions than in cold regions of Europe (Keatinge et al. 2000). In hot regions, people adjust to temperature by strategies such as taking siestas and using outside shutters to prevent sunlight from entering through windows. Countries with the mildest winter climates exhibit the highest effect in winter mortality (Healy 2003). Compared to people in warm regions, people in cold regions keep their houses warmer, dress more warmly, and spend less time outdoors at the same outdoor temperature. People in mild winter regions become careless about cold stress, and protect themselves less effectively against cold. A comparable phenomenon was observed in historical studies dealing with infant mortality. Breschi and Livi-Bacci (1994) and Oris, Derosas, and Breschi (2004:392-393) showed that winter peaks in mortality among infants were more common in climates with milder winters than in harsh climates, where the population had a high capacity for adaptation. In temperate regions, winter was a more dangerous period at the beginning of life than summer; whereas in warmer regions, the effects of winter were much stronger.

The temperature-mortality relationship might be due to *mechanisms other than the direct effects of exposure* of the human body to extreme temperatures. Particularly for historical populations, a number of these indirect effects on mortality might have played an important role. To understand the changes over time in the temperature-mortality relationships, it is essential to pay attention to these factors. The most important of these is the fact that the incidence and virulence of infectious diseases, the leading cause of death, was strongly dependent on temperature. Weather conditions affect the mobility and strength of pathogenic micro-organisms, and of the insects and animals that carry them. In areas and periods in which sanitation is virtually unknown and water supplies are subject to contamination, warm summers promote the spread of infectious diseases through increased proliferation of animal, insect, and bacterial vectors (Galloway 1994). Vector-borne diseases typically exhibit seasonal patterns in which the role of temperature and rainfall is well-documented. Malaria, for example, displays considerable year-to-year variations that can partly be explained by climatic factors. Summer and autumn are strongly associated with diarrhoea and other gastric diseases, the greatest killers of infants under age one. These diseases affected children when they had lost the protection of the mother's milk and were susceptible to contamination through the ingestion of infected food and water (Oris, Derosas, and Breschi 2004). The risks of contaminated milk or water were much higher when temperatures were high (Fildes 1998).

2.2 Vulnerable groups

Vulnerability to heat and cold can be modified by factors such as age, sex, and social class. Most studies that have analyzed differences in vulnerability to temperature fluctuations between groups have focused on differences between men and women and between age groups. Only a limited number of studies contain information on the role of social class, and the evidence on this point is still unclear.

In studies dealing with present-day effects of extreme weather on mortality, a significant variation in the effects of heat and cold is observed according to age. The decrease in thermoregulatory function and appreciation of cold and heat with increasing age is the main reason why the elderly are disproportionately affected by extreme weather conditions (Hajat, Kovats, and Lachowycz 2007). Older people are less able to take care of themselves and are more often bedridden; as a consequence, they are less able to provide cooling. Recent studies have rarely focused on the effects of seasonal variation in temperature on infant mortality. However, Hare, Moran, and Macfarlane (1981), using data for England and Wales for the period 1928-78, observed a trend toward deseasonality for the stillbirth and neonatal death rates before the 1920s; for death rates at ages 3-11 months, no clear trend was discernible.

The question of which gender is more susceptible to weather fluctuations is much in dispute. In the England and Wales study mentioned above, and in the French 2003 heat wave study, women were found to have higher heat-related mortality, reflecting adverse effects of menopause on thermoregulation (Hajat, Kovats, and Lachowycz 2007; Rey et al. 2007). For cold-related mortality, gender differences in an eight-country European study for the years 1988-1992 among people aged 50-75 were not found to be significant (Keatinge et al. 1997).

Relatively few studies have examined the variation in temperature vulnerability by socioeconomic status. Most of these studies do not find an association between socioeconomic deprivation and vulnerability, which has been attributed to the ecological design of many of these studies, and to the crude indices of socioeconomic status used (Ballester, Michelozzi, and Iniguez 2003). McDowall (1981) found that winter excess mortality in England during the 1959-1972 period was higher among semi-skilled and unskilled workers than among other social classes. A study for the period 1993-2003 in the same country (Hajat, Kovats, and Lachowycz 2007) observed very few differences in heat effects according to the level of deprivation of the neighbourhood, and no relationship between cold and deprivation. This was explained by the fact that today people in lower socioeconomic groups do not necessarily live in cooler homes, as housing association and local authority dwellings tend to be well-heated. Donaldson and Keatinge (2003) observed in England and Wales in 1998-2000 that cold-related mortality in men of working age was low in unskilled occupations, but was high in men of retired ages in that same social class. The beneficial effect of work-related factors in this social class was explained by internal heat production from manual work, offering protection against daytime cold stress.

Some of the studies done by medical doctors during periods of extreme heat in the past suggested that infant mortality among children of the poor increased more than among children of the well-to-do (Pous Koolhaas 1869).

Attention has also been paid to the different effects that extreme weather had in urban and rural areas. Urban centres are often particularly affected by heat because of the urban heat island effects, caused by the heat-retaining properties of the densely built and paved urban environments, which result in temperatures being somewhat higher than in the surrounding suburban and rural areas (Rooney et al. 1998). Cold effects might be felt more strongly in more rural areas, where there is greater exposure to outdoor cold as a consequence of reliance on poor public transport (Hajat, Kovats, and Lachowycz 2007).

3. Data

3.1 Mortality data

Numbers of deaths according to day of death, sex, and age at death were collected for one of the 11 Dutch provinces, Zeeland, and covered the period from 1855 to 2006. Nationwide and compulsory birth and death registration based on the rules laid out in the Code Napoleon was introduced in the Netherlands in 1811, at the time of the incorporation of the Netherlands into the French Empire (Vaillant 1893).

For the period 1950-2006, daily mortality data for Zeeland were supplied by the Netherlands' Central Bureau of Statistics. These data are based on the municipal vital registration system, but have been made available as electronic records in a centralized database covering the country as a whole. Data were extracted from this database for Zeeland only. Daily mortality data for an earlier date can also be deduced from the vital registration system, but are only available in a handwritten format in the local death registers. Until recently, studying individual death records was a time-consuming activity, and constraints of time and money forced researchers to focus on small communities and restricted time periods. During the past decade, in the provincial archives in the Netherlands dozens of volunteers and staff have started to enter death records into a database within the framework of the so-called GENLIAS project. The goal of that project is to build up a searchable database, with genealogical information on all marriages, deaths, and births taking place in the Netherlands from the introduction of the vital registration system onwards, until the date these data are no longer in the public domain. Death records enter the public domain after 50 years. Usually records are released in 10-year blocks, and, for that reason, data entry is restricted to deaths taking place before 1956. However, the GENLIAS database is designed to facilitate individual record searches, and is not suitable for extracting large datasets. Thanks to the cooperation of the *Zeeuws Archief,* we were able to use their contribution to GENLIAS, the so-called ISIS database, which covers the whole province of Zeeland for the period before 1950.

Zeeland is in the south-west of the Netherlands. Its territory borders the North Sea, and is in large part below sea level (see Figure 1). The land is protected by a system of river and sea dikes, and consists of a strip of the Flanders mainland bordering Belgium and six former islands, now all connected to each other or to the inland provinces by dams and bridges. Zeeland's landscape, drainage, soil, and accessibility had a profound effect on its types of settlement, the shapes of fields and farms, the use of land, and communications (Lambert 1985, 5-6). For much of its history, the province was a rural area that relied heavily on sea-clay grain farming. But in the second half of the nineteenth century, agricultural modernization was eroding the position of the small farmer and farm labourer (Priester 1998; Wintle 1985). The province was heavily affected by the agrarian depression, leading to very high emigration in the period 1881-1915. The economy of the region started to change after 1900. Tourism developed on a small scale from that time onwards, gaining importance after World War I, but especially after World War II. After 1900, industrialization also started to occur, particularly in Zeeuws-Vlaanderen and Walcheren. After the end of the World War I, the textile and chemical industries became more and more important, but the industrialization did not result in the urbanization of the area. The province had and has no large towns. Like the other Dutch coastal and low-lying areas, the province was characterized by very high mortality until late in the 19th century, in particular by very high infant mortality, which reached levels of 350 deaths before age one per thousand live births. As Table 1 shows, the life expectancy at birth was very low in Zeeland until the middle of the 19th century. It was only in the last decades of the 19th century that Zeeland reached higher values of life expectancy. From that time onwards, Zeeland ranked among the Dutch provinces with the highest life expectancy.

Figure 1: Map of the Dutch province of Zeeland around 1950

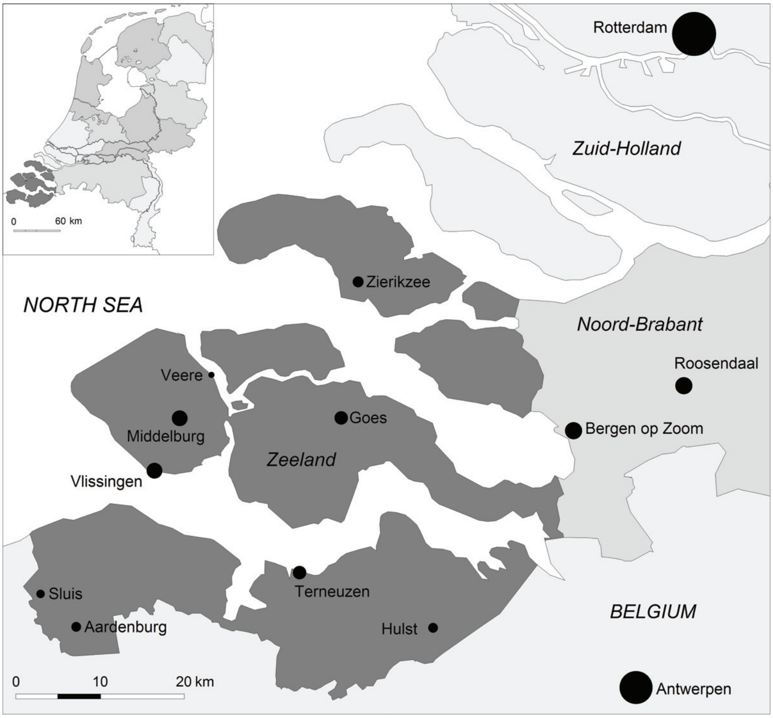

Table 1: Expectation of life at birth, by sex and period in the Dutch province of Zeeland, compared to the maximum and minimum values of all Dutch provinces

	Males			**Females**		
	Zeeland	**All Dutch provinces**		**Zeeland**	**All Dutch provinces**	
		Maximum	**Minimum**		**Maximum**	**Minimum**
1840-51	29. 9	43.5	27.8	31.5	44.7	31.5
1901-02	52.0	54.0	45.1	55.4	55.5	47.3
1956-60	72.4	72.6	70.0	75.2	75.8	73.5
1990-91	73.8	75.5	73.3	81.6	81.6	79.6

Source: Calculations by the authors derived from analyses of data on age and sex structure by provinces at census dates and numbers of deaths by age and sex from vital registration.

The Zeeland mortality database covers the whole province only from 1812 onwards, but in view of the availability of specific temperature data for Zeeland, we restricted the period of study to the years 1855-2006. The data for this period include not only the age at death, the place of death, but also the occupation of the deceased, of the deceased's parents, and of his or her spouse, where applicable. For a part of the period, we will study the effect of temperature fluctuations in more detail using the occupational information.

Ages at death were classified into the following groups: first-year mortality (age at death less than one year), and deaths at ages 1-4, ages 5-19, ages 20-49, ages 50-74, and ages 75 and over.

We categorized all the occupations of the deceased persons, of their spouses, and of their fathers and mothers using a social class system applicable for the period 1855-2006. The social class categorization that we applied is based on a recently developed coding scheme called the *Historical International Standard Classification of Occupations* (HISCO) (Van Leeuwen, Maas, and Miles 2002). HISCO translates occupational descriptions covering a long historical time period, various languages, and various countries into a common code, compatible with the International Labour Organisation's *International Standard Classification of Occupations* (ISCO68) scheme. These historical occupational titles were classified according to a social class scheme recently proposed by Van de Putte and Miles (2005), known as the *Social Power* (SOCPO) scheme. Social power is defined as the ability to influence one's 'life chances' through control of (scarce) resources, and is based on economic factors (e.g., self-employment, skill, and authority) and cultural resources (e.g., non-manual versus manual occupations, and nobility and prestige titles). The merging of economic and cultural power dimensions leads to a scheme with five levels. Level five includes executives responsible for general policy tasks, supra-local businessmen, non-manual super-skilled professionals, and members of the nobility. In level four are the supervisors of skilled workers, local businessmen, and manual super-skilled and non-manual skilled workers. Level three includes supervisors of semi- and unskilled workers, and manual skilled workers. In level two are the self-employed who are locally oriented and have minimal capital, and the semi-skilled workers. Level one comprises the unskilled workers. We denote these groups as, respectively, the elite, the middle class, the skilled workers, the semi-skilled workers, and the unskilled workers. In view of the specific position occupied by farmers in contemporary social class mortality studies, we excluded them from the middle class and placed them in a separate category. A large part of the deceased could not be placed in one of these categories, as they were no longer economically active at the time of their death.

Deaths were also classified according to the rural or urban character of the place in which the deceased person had lived. To classify municipalities as urban or rural, we used information on the number of inhabitants, the percentage of the population working in agriculture in 1889, and the historical designation of a municipality as a town or a village. Differences between urban and rural areas were relatively small, as the countryside was in many aspects closely linked to the cities, and was also rather densely populated, whereas the towns were rather small.

Table 2 presents descriptive statistics for the relevant variables. The total number of deaths in Zeeland over the whole period 1854-2006 was 540,151. The distribution by social class (applicable to 1855-1954 only) shows that a large majority of the people who died belonged to the labouring classes: unskilled and semi-skilled workers in and outside of agriculture constituted around 40% of all deaths, and skilled workers almost 9%. Almost 8% of the deaths were from farm families. The upper and middle classes made up 13% of the total. Around a quarter of all deaths represented infant mortality (below the age of one year), and around 40% of the people who died were aged 50 years or older.

Table 2: Characteristics of the mortality data in the Dutch province of Zeeland

	Period 1855-2006
Number of observations (days)	55517
Number of deaths	540151
Mean number of deaths per day	9.7
Percentage of deaths by sex	
Females	47.6
Males	51.6
Percentage of deaths by age	
Age < 1 year	22.6
Age 1-4 years	5.9
Age 5-19 years	4.3
Age 20-49 years	10.8
Age 50-74 years	26.8
Age 75 years or older	29.5
Percentage of deaths by social class*	
Unskilled workers	33.7
Semi-skilled workers	6.8
Skilled workers	8.6
Farmers	7.8
Middle class (without farmers)	11.5
Elite	1.2
Unknown	30.4
Percentage of deaths by urbanity*	
Place of death is urban	31.3

Notes: * Refers to the period 1855-1954 only

3.2 Climatological data

On December 1, 1848, Christophorus Henricus Didericus Buys Ballot (1817-1890) and Frederick Wilhelm Christiaan Krecke (1812-1882) started their daily and hourly instrumental observations of the weather in the Netherlands, thereby giving the impetus to the creation of the KNMI, the Royal Netherlands Meteorological Institute. From the beginning of the 1850s, readings of the temperature were taken at different stations three times a day, and occasionally four or five times a day. During the first few years, observations were limited to values of wind direction and wind speed, but in later years, elements such as temperature, surface air pressure, relative humidity, cloudiness, and precipitation amount were recorded as well. Of the five climatological stations, one was located in Zeeland, in the city of Vlissingen.

The average annual temperature in Zeeland is usually a little bit higher than in any other part of the country, due to its position at the edge of the North Sea and the higher number of hours of sunshine. In particular, the average minimum temperature was higher in Zeeland than in other parts of the Netherlands. Minimum temperatures below minus 10 degrees Celsius were rare in the province, especially in the most western part of the province. Within the province, the various regions had their own micro-climates because of the varying distance to the North Sea and the estuaries of the river Scheldt. The islands of Walcheren, on which the Vlissingen weather station was located, and of Schouwen had higher minimum temperatures than the remaining parts of the province. The maximum temperatures were, however, lower on both these islands, and on Goeree-Overflakkee, Noord-Beveland, and the western part of Zeeuws-Vlaanderen. The eastern part of Zeeuws-Vlaanderen and Zuid-Beveland had higher July and August maximum temperatures (Heijboer and Nellestijn 2002).

Within the framework of the EC Climatological Research Programme, the KNMI started research on historical instrumental observations of the weather in the Netherlands at the beginning of the year 2000. The objective of that program, called HISKLIM (HIStorical CLIMate), is to make historical meteorological observations from sources in the Dutch language available in a digitized form. (See KNMI 2009).

The weather measurements in the 19th century were made using a self-recording apparatus with a moderate degree of reliability. Changes in measuring positions, measuring instruments, etc., caused discrepancies in the climate time series. For the older observations, e.g., those relating to the period until the 1880s, the times of observation were not standardized: changes were made in the number of times readings were taken, and in the time at which the readings took place. For the Vlissingen station, the temperature (in degrees Celsius) was measured from December 1, 1854 onwards at 9:00, 12:00, and 15:00 hours. From October 7, 1855 onwards, minimum and maximum temperatures were recorded. From December 1, 1857, temperature measurements took place at 8:00, 12:00, and 15:00; and from April 1, 1859 onwards, temperatures were recorded at 8:00, 12:00, and 14:00. But two years later, on April 1, 1861, the recording took place at 8:00, 14:00, and 20:00.

To improve the utility of the climate time series, the data for daily mean temperature and maximum and minimum temperature have to be homogenized. Formally, daily mean temperatures have to be calculated from 24 hourly values each day, but these hourly readings are not available for historical stations. Various procedures have been developed to calculate the temperature for every hour of a given day from a small number (at least two) of regular readings on the same day (Van der Hoeven 1992; Van Engelen and Geurts 1983). These estimation procedures have been tested on temperature records of the principal station of the KNMI at De Bilt for the period 1971-1980. We used the method of Van Engelen and Geurts (1983), a slightly adapted version of Parton and Logan (1981); (see Van Duin 2008).[6] This made it possible to calculate homogeneous mean daily temperature and the maximum and minimum temperatures from 1854 until 1956.

4. Method

Methods used to assess temperature-related mortality have varied considerably, and so have the ways in which results have been presented. The medical doctors who studied the relationship between temperature fluctuations and infant mortality in the first decade of the 20th century used almost exclusively simple descriptive and graphical methods. To model the association between temperature and mortality, we adopted here an approach similar to one used in a recent study of the impact of heat waves and cold spells on mortality in the Netherlands during the period 1979-1997 by Huynen et al. (2001). The daily total numbers of deaths, as well as the number of deaths in selected age groups and social classes, were related to the daily average temperatures using regression models for the whole dataset (January 1, 1855 to December 31, 2006) and subsets (25-year periods, heat waves and cold spells), controlling for the long-term time trend and seasonal pattern. However, to account for overdispersion of our dependent variables in the dataset, we use negative binomial regression instead of ordinary Poisson regression (see Cameron and Trivedi 1998 or McCullagh and Nelder 1989). As many studies have shown, seasonality is changing over time both in the Netherlands (Kunst, Looman, and Mackenbach 1991) and other countries (e.g., Eilers et al. 2008; Lerchl 1998; Marcuzzi and Tasso 1992; Seretakis et al. 1997). To account for the

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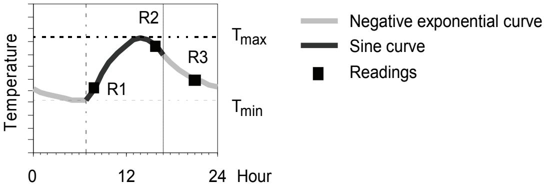
[6] The method estimates a daily temperature (T) pattern modeled by a sine curve (for temperature rise in the morning and afternoon cooling down), and a negative exponential curve (for cooling down in the evening and at night) with parameters estimated by Van Engelen and Geurts 1983 (for time of minimum and maximum temperature, times of sunrise and sunset and tempo of cooling down in the evening) using two or three readings (R):



varying cyclical seasonal pattern, we used the following general expression of the Gampe and Rau (2004) seasonal time series modulation model to estimate the long-term time trend and seasonality for raw counts (see Eilers et al. 2008):

$$\log(\mu_t) = \upsilon_t + f_t \cos(\omega t) + g_t \sin(\omega t)$$

where $t = 1,\ldots,T$ and $\omega = 2\pi/p$ (where p is the period, in our analyses the number of days per year). The smooth long-term time trend υ_t to account for long-term trends resulting from changes in, for example, population size and structure, and socioeconomic and health care conditions were included as a restricted seven knots cubic smoothing spline. The f_t and g_t parameters, describing the local amplitudes of the cosine and sine waves, were included as restricted seven knots cubic smoothing splines of the annual f and g estimates of the Gampe-Rau model.

To account for the V-like relationship between mortality and temperature (see, for example, Huynen et al. 2001), average daily temperatures within the model were measured by two complementary variables, heat (zero if average temperature was lower than the optimum value, otherwise average temperature minus optimum value) and cold (zero if average temperature was higher than the optimum value, otherwise optimum value minus average temperature). The optimum value corresponds to the average value of the temperature with the lowest mortality level found by Huynen et al. (2001), for the Netherlands, viz. 16.5° C.

Temperature variables were also constructed in line with Huynen et al. (2001). Lag temperature variables were calculated by averaging values for heat and cold over lag periods that increased exponentially in size: lag times 1-2, 3-6, 7-14 and 15-30 days.

The general form of the regression model used can be described by

$$\log(y_\mathrm{i}) = \beta_0+\beta_1 h_\mathrm{i}+\beta_2 h_{\mathrm{i-1,i-2}}+\beta_3 h_{\mathrm{i-3,i-6}}+\beta_4 h_{\mathrm{i-7,i-14}}+\beta_5 h_{\mathrm{i-15,i-30}}+\beta_6 c_\mathrm{i}+\beta_7 c_{\mathrm{i-1,i-2}}+ \beta_8 c_{\mathrm{i-3,i-6}}+\beta_9 c_{\mathrm{i-7,i-14}}+\beta_{10} c_{\mathrm{i-15,i-30}}+\beta_{11} s_\mathrm{i}$$

where y_i (dependent) is the number of deaths on day i, h_i (heat) is the average value for heat on day i, $h_{\mathrm{i-1,i-2}}$ to $h_{\mathrm{i-15,i-30}}$ the average heat values for lag times 1-2 to 15-30, c_i (cold) is the average heat values for cold on day i, $c_{\mathrm{i-1,i-2}}$ to $c_{\mathrm{i-15,i-30}}$ the average cold values for lag times 1-2 to 15-30, s_i (seasonality) is the sequential value of the long-term seasonal trend for day i estimated beforehand by the Gampe-Rau model. $\beta_0 \ldots \beta_j$ are the regression coefficients.

Negative binomial regression analyses were applied to both the average daily total number of deaths, as well as to the average daily number of deaths by sex, age group (< 1 year, 1-4 years, 5-19 years, 20-49 years, 50-74 years, and 75 years or older) and social class (unskilled workers, semi-skilled workers, skilled workers, farmers, middle class, and elite). Additionally, regression analyses with respect to the average daily total number of deaths were applied to both shorter (25-year interval) time periods (1855-1879, 1880-1904, 1905-1929, 1930-1954, 1955-1979, and 1980-2006) and years with heat waves and cold spells.

According to the official definition by the Netherlands Royal Meteorological Institute (KNMI) a heat wave is defined as a period of at least five days, each of which has a maximum temperature of at least 25° C (so-called summer days), including at least three days with a maximum temperature of at least 30° C (so-called tropical days) measured at the De Bilt station located in the centre of the Netherlands. Applying this definition to the Vlissingen station located in the province of Zeeland, there were seven heat waves in Zeeland in the period 1855-2006. However, the summers of 1868 and 1884, for instance, both had two tropical days only, but long periods of summer days. In both years there was a strong increase in mortality in the summer period. To expand the number of extreme hot periods in the province of Zeeland, a slightly different definition of a *heat wave* was adopted: a period of at least seven days, each of which has a maximum temperature of at least 25° C; or a period of at least three days, each of which has a maximum temperature of at least 30° C (measured at the Vlissingen station). According to this definition, there were 15 heat waves in Zeeland in the period 1855-2006 (including the five official heat waves), viz. the summers of 1856, 1858, 1868, 1871, 1872, 1884, 1911, 1947, 1948, 1975, 1976, 1997, 2002, 2003, and 2006. In the analyses presented below, the *summer period* includes the warmest months in the Netherlands: June, July, August, and September.

There is no official definition of a cold spell by the Netherlands Royal Meteorological Institute. The definition adopted for a cold spell is based on both the daily minimum and maximum temperatures, and is supposed to provide a number of cold spells similar to the number of heat waves (as defined above) in the same period. A *cold spell* is therefore a period of at least 15 days, each of which has a minimum temperature less than 0° C (so-called frost days); and a period of at least 10 days, each of which has a maximum temperature less than 0° C (so-called ice days) measured at the Vlissingen station. According to this definition, there were 14 cold spells in the period 1855-2006, viz. the winters of 1854-55, 1860-61, 1870-71, 1878-79, 1890-91, 1894-95, 1916-17, 1928-29, 1946-47, 1953-54, 1955-56, 1962-63, 1986-87, and 1996-97. In the analyses presented below, the *winter period* includes the coldest months in the Netherlands: December, January, and February.

For graphical presentation, (natural) cubic smoothing splines (cubic splines constrained to be linear beyond the data range) were used to construct graphs of mortality as smoothed functions of temperature with one degree of freedom for every 5° C.

All analyses were conducted using Stata version 10 (StataCorp. 2007).

5. Descriptives

Table 3 presents descriptive statistics for the variables on mortality and temperature by 25-year period. The total number of deaths decreases from 129,400 in the period 1855-1879 to 65,502 in the period 1930-1954. Thereafter, the number of deaths increases again. The distribution of deaths by age group shows a shift from younger to older age groups. In the first two periods, more than 30% of all deaths concerned infant mortality (mortality below the age of one year). In the last two periods, the share of total mortality represented by the oldest age groups, 50-74 years and 75 years and older, increased to 90% and more. The distribution by social class shows that, in the first period, a large majority of the deaths belonged to the labouring classes: unskilled and semi-skilled workers in and outside agriculture constituted around 55% of all deaths, and skilled workers represented almost 10% of deaths. Almost 9% of the deaths were from farming families. The upper and middle classes made up 15% of the total. Due to an enormous increase of the number of deaths with social class unknown (that is, either unknown or no particular occupation in the case of women), the share of the other social classes is much lower than for the labouring classes.

Table 3: Characteristics of the mortality and temperature* data in the Dutch province of Zeeland by period, 1855-2006**

	Period					
	1855-79	**1880-04**	**1905-29**	**1930-54**	**1955-79**	**1980-06**
Number of observations (days)	9131	9131	9131	9131	9131	9862
Number of deaths	129416	100259	78826	65502	70976	95172
Mean number of deaths per day	14.2	11.0	8.6	7.2	7.8	9.7
Percentage of deaths by sex						
Females	48.5	48.0	48.0	47.1	45.0	47.9
Males	51.5	51.8	50.3	49.2	54.8	52.1
Percentage of deaths by age						
Stillbirths	7.8	7.9	6.9	6.0		
Age < 1 year	33.6	30.6	18.6	5.4	2.3	0.6
Age 1-4 years	12.3	9.1	5.6	2.0	0.9	0.3
Age 5-19 years	7.2	6.1	5.4	3.5	1.3	0.5
Age 20-49 years	15.2	12.1	13.3	12.1	5.6	4.5
Age 50-74 years	17.6	21.5	27.1	37.5	37.4	29.1
Age 75 years or older	6.1	12.6	22.9	33.3	52.5	65.0

Table 3: (Continued)

Percentage of deaths by marital state						
Never married	8.5	7.5	6.3	3.2	-	-
Married	19.8	23.2	30.4	41.5	-	-
Divorced	0.0	0.1	0.2	0.4	-	-
Widowhood	11.4	15.2	22.3	28.8	-	-
Other (children/unknown)	60.2	54.0	40.8	26.1	-	-
Percentage of deaths by social class						
Unskilled workers	47.1	37.3	25.4	11.9	-	-
Semi-skilled workers	8.0	7.2	6.1	4.5	-	-
Skilled workers	9.5	10.0	7.7	5.8	-	-
Farmers	8.6	7.9	7.6	6.1	-	-
Middle class (without farmers)	13.3	13.7	9.4	7.0	-	-
Elite	1.3	1.2	1.1	1.3	-	-
Unknown	12.2	22.7	42.7	63.3	-	-
Percentage of deaths by urbanity						
Place of death is urban	27.2	31.2	32.6	38.2	-	-
Mean temperatures (° C)						
Daily (24 hour) mean	9.9	10.0	10.1	10.0	9.9	10.7
Daily (24 hour) minimum	7.0	7.5	8.1	7.4	7.4	8.3
Daily (24 hour) maximum	12.3	12.4	12.1	12.7	12.6	13.5
Mean number of hot/cold days per year						
Summer days (max >= 25 ° C)	9.0	7.6	7.2	10.0	7.7	15.8
Tropical days (max >= 30 ° C)	0.6	0.2	0.7	0.6	0.7	1.5
Frost days (min < 0 ° C)	36.4	37.8	25.8	34.8	33.0	24.3
Ice days (max < 0 ° C)	10.0	8.6	8.0	9.2	7.3	5.0

Notes: * Measurements from Vlissingen station
** No temperature measurements from October 1944 to July 1945

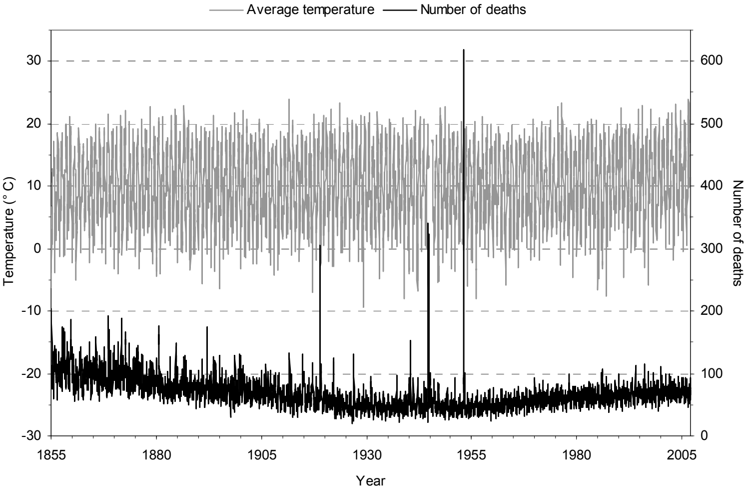
The average daily 24-hour temperature was rather stable (around 10° C) throughout the consecutive periods. The number of tropical days was relatively low in the period 1880-1904, and was relatively high in the last period. On the other hand, the number of frost days was relatively low in the periods 1905-1929 and 1980-2006.

The time span of January 1, 1855 to December 31, 2006 covers some periods with exceptional high mortality, viz. the Spanish flu pandemic, which occurred in Zeeland in 1918; the Second World War, which lasted from May 1940 to November 1944 in Zeeland; and the North Sea flood disaster starting in the night of January 31 –

February 1, 1953. Figure 2 shows both the number of deaths and the seasonal pattern of the temperature data (aggregated in weekly data). No temperature measurements are available from the Vlissingen station for the period of October 1944 to July 1945. Both the periods with exceptional high mortality and the periods with missing temperature data were excluded from the regression analyses. Summarizing, the following periods were excluded from the analyses:

October 1918 - November 1918	:	Spanish flu pandemic
May 1940 - November 1944	:	World War II
October 1944 - July 1945	:	No temperature measurements available from the Vlissingen station
February 1953	:	North Sea flood disaster

Figure 2: **Weekly mortality and weekly average 24-hour temperature in the Dutch province of Zeeland, 1855-2006***

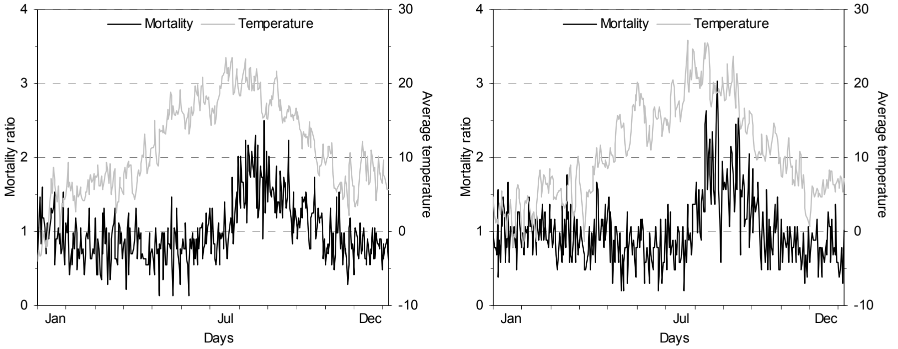


Notes: * no temperature measurements available for October 1944 – July 1945.

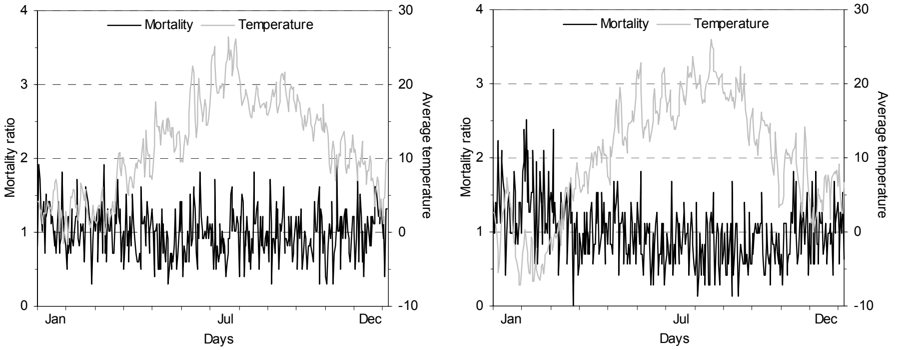
Figure 3 shows the daily numbers of deaths and daily average temperatures for some specific years characterised by heat waves. The first year, 1868, had no heat wave according to the official Dutch definition, since the year had two tropical days only. However, 1868 was amongst the highest with respect to the number of summer days: 29 days (with the longest period of seven consecutive summer days in a row). Both 1868 and 1884 show mortality peaks in the month of August. The other three years, 1911, 1947, and 2006, were among the hottest summers in the period 1855-2006, both in terms of summer days (32 in 1911, 35 in 1947, 33 in 2006) and tropical days (11 in 1911, four in 1947, and seven in 2006). Mortality in 1911 shows peaks in August and September similar to the pattern in 1868. However, this mortality pattern is more or less absent in the years 1947 and 2006.

Figure 3: Daily mortality[*] and average 24-hour temperature (°C) in the Dutch province of Zeeland in 1868, 1911, 1947, and 2006

(a) 1868 (b) 1911



(c) 1947 (d) 2006



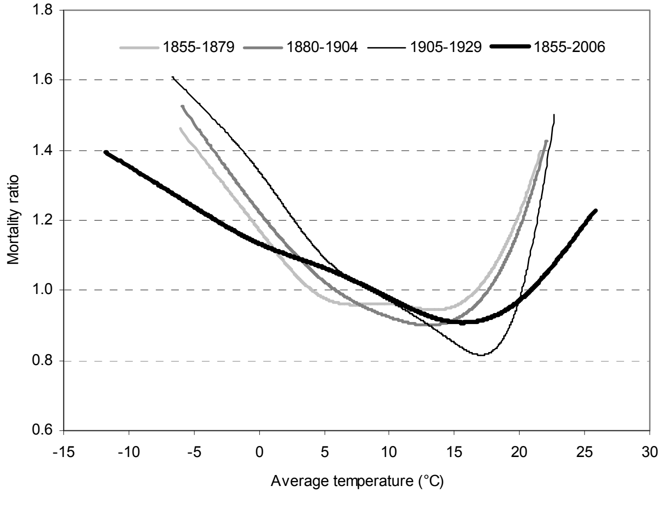
Notes: * mortality ratio = observed number of deaths per day / average number of deaths in the same year

6. Results

Figure 4 shows the relationship between mortality and temperature by 25-year period. Mortality tends to increase both at low and high temperatures. However, the V-like relationship between mortality and temperature found by Huynen et al. (2001) for the Netherlands as a whole in the period 1979-1997 is less prominent in Zeeland in the period 1855-2006. Huynen et al. (2001) found an optimum value of 16.5° C for all-cause mortality, which is more or less in line with the patterns shown in Figure 4. According to the cubic smoothing splines, in the first two periods, 1855-1879 and 1880-1904, the optimum temperature tends to be slightly below 15° C. In the periods 1905-1929 and 1930-1954, the optimum temperature tends to be around 17° C. In the latter periods, 1955-1979 and 1980-2006, the optimum temperature tends to be slightly below 16° C.

Figure 4: Restricted cubic smoothing splines of daily mortality ratio* by average temperature and period in the Dutch province of Zeeland

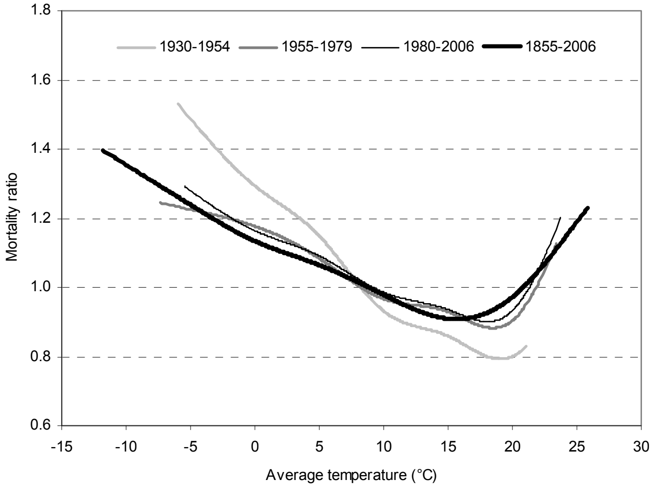
(a)



Notes: * mortality ratio = observed number of deaths per day / average number of deaths in the same year.

Figure 4: (Continued)

(b)



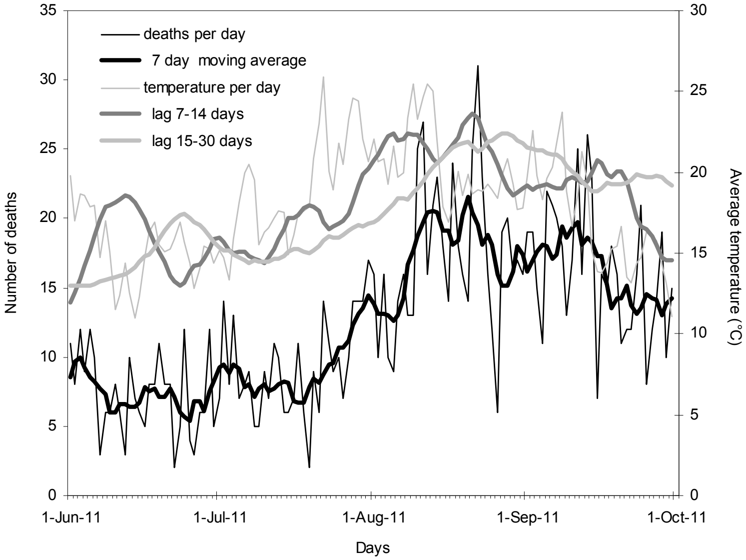
Notes: * mortality ratio = observed number of deaths per day / average number of deaths in the same year.

As has been mentioned by several studies, the effects of extreme heat or cold may consist of a more or less instantaneous effect and a more delayed effect. Two examples are shown to provide an idea of these effects in specific years. Figure 5 shows mortality and temperature in one of the hottest summers in the period 1855-2006, the summer of 1911. During this summer—that is, the months June to September—there were 31 summer days (and a maximum of seven consecutive summer days) and 11 tropical days (and a maximum of three consecutive tropical days). On average, a summer in the period 1905-1929 had around seven summer days and less than one tropical day (see Table 3).

Figure 5 clearly shows that mortality peaks after extreme hot periods. After a first heat wave starting around July 20, mortality started to increase after one week. Temperature peaks around July 29 and August 11 were again followed by mortality peaks on August 11 and 22. Both the average temperatures for lag days 7-14 and 15-30 show patterns that are more or less in line with the mortality pattern.

A negative binomial regression between daily mortality and two temperature variables (the average temperatures minus the optimum temperature on lag days 1-2 and lag days 15-30) resulted in regression coefficients of 0.0563 (lag 1-2) and 0.1412 (lag 15-30) implying a 5.8% and 15.2%[7] increase in the number of deaths per day per degree Celsius respectively ($R^2 = 0.49$)[8]. This combination of lag temperatures proved to be the best fit, and both independent variables were significant ($p<0.01$). The effect of heat on mortality shows no strong relationship with age, except for infant mortality (age <1 year, $R^2 = 0.51$; other age groups R^2 lower than 0.12).

Figure 5: Daily mortality, 7-day moving average of mortality, daily average 24-hour temperature and daily average temperature for lag days 7-14 and 15-30 in the Dutch province of Zeeland in the summer of 1911



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[7] Calculated as transformation of the regression coefficient β using the formula 100 x (e^{β} - 1)

[8] Since the statistical package we used does not produce a proper R^2 measure for negative binomial regression models, we use an ordinary squared multiple correlation coefficient with respect to the observed dependent variable and estimated values. Cameron and Windmeijer (1996) already indicated that "R^2 measures of goodness of fit for count data are rarely, if ever, reported in empirical studies or by statistical packages." However, they conclude that "use of any of these measures (…) is more informative than the current practice of not computing an R^2."

Figure 6 shows mortality and temperature in one of the coldest winters in the period 1855-2006, the winter of 1890-1891. During this winter—that is, the months December to February—there were 62 frost days (and a maximum of 38 consecutive frost days) and 30 ice days (and a maximum of 13 consecutive ice days). On average, a winter in the period 1880-1904 had around 38 frost days and slightly fewer than nine ice days (see Table 3). In Figure 6, both the average temperatures for lag days 7-14 and 15-30 show patterns more or less in line with the mortality pattern. A negative binomial regression between daily mortality and two temperature variables (the optimum temperature minus the average temperatures on lag days 1-2 and lag days 15-30) resulted in regression coefficients of 0.0191 (lag 1-2) and 0.0253 (lag 15-30) implying a 1.9% and 2.6% increase, respectively, in the number of deaths per day per degree Celsius ($R^2 = 0.29$). This combination of lag temperatures proved to be the best fit. A model including lag days 7-14 instead of lag days 15-30 performed almost equally. However, the relationship between the cold spell and mortality appears to be weaker than the relationship between the heat wave and mortality. The effect of cold on mortality shows some correlation with age: age group 50-74 years $R^2 = 0.20$; 75+ years $R^2 = 0.24$; other age groups R^2 below 0.02).

Next, the results of the regression model explained in Section 4 will be presented. First the model will be applied to all heat waves and cold spells as defined in Section 4. Table 4 presents the regression coefficients of this model applied to all years with either a heat wave or a cold spell. The model was applied to total mortality (total number of deaths per day), numbers of deaths by sex, numbers of deaths by age group, and numbers of deaths by social class. All models were calculated with the full model, including seasonal time trend.[9]

The regression coefficients for heat with respect to total mortality show a positive effect, both instantaneous and delayed, except for the not significant coefficient for lag-days 3-6. The 0.0677 effect of heat for the lag-days 15-30 means that a 1° C increase in temperature above the optimum temperature is associated with a 7% increase in the number of deaths on a day. The regression coefficients for cold show positive effects for the delayed temperature changes for lag days 1-2, 3-6, and 7-14 as well. In this case, the immediate effects of the same day and of the lag days 1-2 and 15-30 are not significant. The pattern appears to be similar for men and women. [10]

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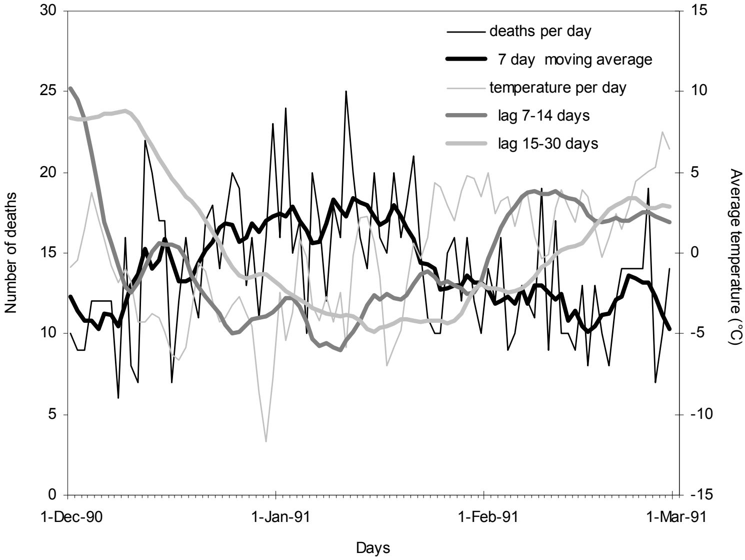
[9] As a measure of whether this represents a good fit, we used, in addition to the ordinary squared multiple correlation coefficient R^2, an overdisperion based R^2_α developed for negative binomial models (Miaou 1996; Miaou, Lu, and Lum 1996). $R^2_\alpha = 1 - (\alpha / \alpha_{max})$, with α_{max} estimated from a negative binomial model with a constant term and overdispersion parameter only. A smaller overdispersion parameter signifies a better fit.

[10] Huynen et al. (2001) applied a similar model to national data of the Netherlands covering the period 1979-1997 using slightly different definitions of heat waves and cold spells. Applying the same definitions to the

Figure 6: Daily mortality, 7-day moving average of mortality, daily average 24-hour temperature and daily average temperature for lag days 7-14 and 15-30 in the Dutch province of Zeeland in the winter of 1890-1891



For most age groups, the relationships between temperature and mortality are rather weak, with the exception of infant mortality (age <1 year). Particularly with respect to infant mortality, there is a relatively strong relationship between heat and mortality.

The strongest relationship between temperature and mortality by social class applies to unskilled workers, again both instantaneous and delayed.

Table 5 presents the regression coefficients of the regression model applied to all summers and winters in the period 1855-2006. Though the relationships between mortality and temperature, judged by the ordinary R^2, are weaker than the similar ones in Table 4, the overall pattern is more or less the same. Again, infant mortality and deaths among unskilled workers show relatively strong correlations with temperature.

Zeeland data reduces the number of heat waves and cold spells in our analysis (to seven and two, respectively), but produces similar outcomes as in Table 4 ($R^2 = 0.42$ and $R^2_\alpha = 0.73$ for total mortality).

Table 4: Regression coefficients of negative binomial regression between daily mortality and temperature with different time lags controlled for long-term seasonal mortality trend in the Dutch province of Zeeland during heat waves and cold spells in the period 1855-2006[a]

	Total[b]	Sex		Age groups						Social class[c]			
	mortality	females	males	< 1	1-4	5-19	20-49	50-74	75+	unskilled	skilled	Farmers	mid/high
Number of Observations	5766	5761	5761	5761	5761	5761	5761	5761	5761	3851	3851	3851	3851
Mean no. of deaths (±SD)	10.8 (±5.2)	5.2 (±3.1)	5.6 (±3.2)	2.4 (±3.4)	0.8 (±1.2)	0.5 (±0.9)	1.2 (±1.4)	2.6 (±1.8)	2.8 (±2.9)	4.3 (±3.7)	1.0 (±1.2)	0.9 (±1.0)	1.5 (±1.5)
Heat													
day 0	0.0233**	0.0280**	0.0202**	0.0354*	0.0365	0.0215	0.0366*	0.0242*	0.0201	0.0314**	-0.0024	0.0251	0.0396*
lag-days 1-2	0.0164**	0.0146	0.0162*	0.0173	0.0372	-0.0018	0.0053	0.0085	0.0420**	0.0010	0.0751**	0.0267	0.0070
lag days 3-6	-0.0024	-0.0071	0.0015	0.0120	-0.0317	0.0025	-0.0316	-0.0057	0.0092	0.0221	-0.0219	-0.0228	0.0098
lag days 7-14	0.0251**	0.0243**	0.0284**	0.1196**	-0.0046	-0.0271	0.0057	-0.0001	0.0023	0.0645**	0.0917**	0.0744**	0.0704**
lag days 15-30	0.0677**	0.0687**	0.0696**	0.1922**	0.0738**	-0.0075	-0.0389*	0.0351**	0.0649**	0.1580**	0.1299**	0.1233**	0.1151**
Cold													
day 0	-0.0029	-0.0058	-0.0006	-0.0102	-0.0183	0.0029	-0.0094	0.0025	-0.0066	-0.0098	-0.0141	0.0089	-0.0049
lag days 1-2	0.0062	0.0091	0.0041	0.0082	0.0129	-0.0316*	0.0112	0.0100	0.0056	0.0109	0.0328**	-0.0101	-0.0048
lag days 3-6	0.0100**	0.0095*	0.0102**	0.0171	-0.0119	0.0158	-0.0004	0.0052	0.0159*	0.0094	0.0050	0.0061	0.0242**
lag days 7-14	0.0075**	0.0099**	0.0056	0.0005	0.0039	-0.0142	0.0022	0.0154**	0.0228**	-0.0021	0.0028	0.0200*	-0.0015
lag days 15-30	-0.0076	-0.0080**	-0.0075**	-0.0367**	-0.0110	0.0101	-0.0049	-0.0038	0.0156**	-0.0072	-0.0167*	-0.0161	-0.0011
Seasonal trend	0.0963**	0.0996**	0.0975**	0.3548**	0.3444**	0.2609**	0.1918**	-0.0031	-0.1725**	0.2341**	0.1397**	0.1323**	0.1469**
α	0.0360**	0.0430**	0.0356**	0.6884**	0.3537**	0.2580**	0.1359**	0.0538**	0.4945**	0.1004**	0.0526*	0.0555**	0.0964**
R^2	0.4122	0.2955	0.3049	0.4237	0.2716	0.1870	0.2638	0.0708	0.1048	0.5201	0.1728	0.1384	0.2066
R^2_α	0.7227	0.7073	0.7302	0.6892	0.7778	0.7508	0.7580	0.3726	0.2903	0.8507	0.8172	0.7920	0.7073

Notes: a Except October-November 1918, May 1940-July 1945, and February 1953

b All models calculated with full model including seasonal time trend and temperature during different time lags; mid/high = middle class + elite

c Due to data unavailability models applied to period 1855-1955 only

* Significant ($p<0.05$), ** Significant ($p<0.01$)

α = overdisperion parameter, R^2 = ordinary correlation coefficient between observed and estimated dependent variable, overdisperion based $R^2\alpha = 1 - (\alpha / \alpha max)$, with αmax estimated from model with a constant term and overdispersion parameter only (see Miaou, 1996)

Table 5: Regression coefficients of negative binomial regression between daily mortality and temperature with different time lags controlled for long-term mortality trend and season in the Dutch province of Zeeland during all summers and winters in the period 1855-2006 [a]

	Total[b]	**Sex**		**Age groups**						**Social class**[c]			
	mortality	**females**	**males**	**< 1**	**1-4**	**5-19**	**20-49**	**50-74**	**75+**	**unskilled**	**skilled**	**farmers**	**mid/high**
Number of Observations	5766	5761	5761	5761	5761	5761	5761	5761	5761	3851	3851	3851	3851
Mean no. of deaths (± SD)	9.8 (±4.6)	4.7 (±2.8)	5.1 (±2.8)	1.9 (±2.8)	0.6 (±1.0)	0.4 (±0.7)	1.0 (±1.2)	2.6 (±1.7)	2.8 (±2.7)	3.6 (±3.2)	0.9 (±1.1)	0.8 (±1.0)	1.3 (±1.4)
Heat													
day 0	0.0263**	0.0266**	0.0260**	0.0298**	0.0492**	0.0312**	0.0273**	0.0212**	0.0292**	0.0311**	0.0272**	0.0281**	0.0341**
lag days 1-2	0.0045	0.0043	0.0044	-0.0012	-0.0009	-0.0075	-0.0088	0.0030	0.0246**	-0.0031	0.0162	0.0037	-0.0054
lag days 3-6	-0.0031	-0.0009	-0.0044	0.0142	-0.0088	0.0032	-0.0169*	-0.0079	0.0008	0.0143*	0.0057	-0.0113	0.0151
lag days 7-14	0.0229**	0.0239**	0.0233**	0.0856**	-0.0046	-0.0118	-0.0055	-0.0008	0.0192**	0.0531**	0.0572**	0.0456**	0.0593**
lag days 15-30	0.0530**	0.0541**	0.0538**	0.1545**	0.0439**	-0.0137	-0.0174	0.0126*	0.0563**	0.1183**	0.1218**	0.1034**	0.0907**
Cold													
day 0	-0.0074**	-0.0100**	-0.0049**	-0.0158**	-0.0182**	-0.0147*	-0.0065	-0.0044*	-0.0050	-0.0128**	-0.0068	-0.0057	-0.0115**
lag days 1-2	0.0090**	0.0110**	0.0075**	0.0189**	0.0129*	0.0091	0.0061	0.0078**	0.0084*	0.0167**	0.0131*	0.0035	0.0131**
lag days 3-6	0.0096**	0.0089**	0.0100**	0.0135**	-0.0072	0.0035	-0.0017	0.0116**	0.0165**	0.0046	0.0069	0.0066	0.0120**
lag days 7-14	0.0063**	0.0087**	0.0039*	-0.0113**	-0.0016	-0.0196**	0.0025	0.0123**	0.0214**	-0.0032	0.0029	0.0075*	-0.0026
lag days 15-30	-0.0075**	-0.0064**	-0.0089**	-0.0423**	-0.0029	0.0054	-0.0058	0.0002	0.0145**	-0.0177**	-0.0165**	-0.0068	-0.0083**
Seasonal trend	0.0994**	0.1045**	0.0990**	0.3664**	0.3530**	0.2458**	0.1806**	-0.0119	-0.1516**	0.2367**	0.1505**	0.1593**	0.1611**
α	0.0287**	0.0351**	0.0308**	0.6087**	0.2949**	0.2463**	0.1228**	0.0374**	0.4213**	0.0821**	0.0511**	0.0511**	0.0672**
R^2	0.3702	0.2608	0.2502	0.4065	0.2705	0.1469	0.2068	0.0547	0.0972	0.5085	0.1442	0.1077	0.1970
R^2_α	0.7300	0.7186	0.7139	0.6970	0.8126	0.7176	0.7209	0.3989	0.2413	0.8596	0.8054	0.7696	0.7697

Notes:
a Except October-November 1918, May 1940-July 1945, and February 1953
b All models calculated with full model including seasonal time trend and temperature during different time lags; mid/high = middle class + elite
c Due to data unavailability models applied to period 1855-1955 only
* Significant ($p<0.05$), ** Significant ($p<0.01$)
α = overdisperion parameter, R^2 = ordinary correlation coefficient between observed and estimated dependent variable, overdisperion based $R^2\alpha = 1 - (\alpha / \alpha max)$, with αmax estimated from model with a constant term and overdispersion parameter only (see Miaou, 1996)

Table 6 presents the regression coefficients of the regression model applied to all summers and winters by 25-year interval over the period 1855-2006. The results indicate that the effect of heat becomes less important over the course of time, particular in the period 1930-1955. Since infant mortality appears to have a relatively strong relationship with temperature, the results of the regression with infant mortality and 25-year period are included in the table as well. The relationship between infant mortality and temperature (heat in particular) starts disappearing in the period 1930-1955 (both declining R^2 and R^2_α). A similar regression applied to age group 75 years and older (not shown in the table) indicates an increasing correlation between old age mortality and temperature (more or less stable R^2 and increasing R^2_α), mainly due to delayed cold related mortality (lag days 7-14 and 15-30), and to a lesser extent instantaneous heat related mortality.

As a reference, we applied the same regression model to Dutch national mortality and temperature data (daily mortality data only available for the period from 1950 onwards). This produces remarkable differences in the relationship between mortality and temperature appears to be much stronger in the national data set ($R^2 = 0.70$ for 1955-1979 and $R^2 = 0.58$ for 1980-2006). Though average daily temperatures are slightly higher in Zeeland, the time pattern is similar to the national one, since the national average daily temperatures (measured at the De Bilt station) highly correlate with the Zeeland average daily temperatures ($R^2 = 0.96$). In this period, temperature-related excess mortality appears to be much less important in the province of Zeeland than in the entire country.[11] While the reasons for this finding are unclear, it shows that, even in a relatively small country like the Netherlands, micro-climatical differences are important.

7. Discussion

Our analysis is, to our knowledge, the first one in which the relationship between temperature and mortality over a long historical period was tested with rigorous statistical methods on the basis of rather refined temperature and mortality data. The models that we applied fitted our observations rather well, especially when applied to heat waves and cold spells only. Our conclusions can be summarized as follows.

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[11] As a test we applied the Zeeland and Dutch national temperature data to both the Dutch national and Zeeland mortality data and found very similar results (low correlation between national temperatures and Zeeland mortality; high correlation between Zeeland temperatures and national mortality).

Table 6: Regression coefficients of negative binomial regression between daily total and infant mortality and temperature with different time lags controlled for long-term mortality trend and season in the Dutch province of Zeeland during all summers and winters per period[a]

	Periods[b]						Age < 1 year[b]					
	1855-1879	1880-1904	1905-1929[a]	1930-1954[a]	1955-1979	1980-2006	1855-1879	1880-1904	1905-1929[a]	1930-1954[a]	1955-1979	1980-2006
Number of observations	5306	5306	5291	4126	5306	5731	5306	5306	5291	4126	5306	5731
Mean no. of deaths (±SD)	14.2 (±5.1)	11.2 (±4.2)	8.3 (±3.8)	6.8 (±3.1)	7.8 (±3.1)	9.7 (±3.3)	5.0 (±3.4)	3.6 (±2.7)	1.6 (±1.7)	0.4 (±0.7)	0.2 (±0.4)	0.1 (±0.3)
Heat												
day 0	0.0270**	0.0310**	0.0337**	0.0290**	0.0323**	0.0116*	0.0295**	0.0333**	0.0199	0.0256	0.0644	0.0031
lag days 1-2	-0.0043	-0.0063	0.0033	0.0108	0.0127	0.0181**	0.0028	-0.0073	0.0077	0.0225	-0.0572	0.0230
lag days 3-6	-0.0013	0.0081	0.0093	-0.0168	-0.0167*	-0.0095	0.0151	0.0321**	0.0296	-0.0538	-0.0678	0.0091
lag days 7-14	0.0469**	0.0599**	0.0296**	-0.0087	-0.0121	-0.0039	0.1047**	0.1110**	0.1010**	-0.0204	0.0024	-0.1110
lag days 15-30	0.1308**	0.0953**	0.0576**	0.0026	-0.0032	0.0013	0.2052**	0.1892**	0.1945**	0.1087*	-0.0249	0.0748
Cold												
day 0	-0.0055*	-0.0071*	-0.0108**	-0.0095*	-0.0100**	-0.0014	-0.0052	-0.0074	-0.0361**	-0.0100	-0.0114	-0.0710
lag days 1-2	0.0169**	0.0143**	0.0112**	0.0094*	0.0000	-0.0018	0.0242**	0.0165*	0.0195*	0.0214	0.0379	0.0177
lag days 3-6	0.0081**	0.0078**	0.0114**	0.0095*	0.0094**	0.0124**	0.0192*	0.0120*	0.0203**	0.0157	-0.0169	0.0367
lag days 7-14	0.0061*	0.0033	0.0092**	0.0088**	0.0100**	0.0034	-0.0096*	-0.0021	-0.0259**	0.0140	0.0358	0.0369
lag days 15-30	-0.0160**	-0.0001	-0.0171**	0.0097**	-0.0114**	-0.0015	-0.0485**	-0.0328**	-0.0653**	-0.0289*	-0.0229	0.0018
Seasonal trend	0.0596**	0.0440**	0.1434**	0.0398**	0.1808**	0.1048**	0.0546**	0.0824**	0.5446**	0.2687**	-0.3645**	-0.5856**
α	0.0277**	0.0266**	0.0313**	0.0195**	0.0048*	0.0025	0.0691**	0.1019**	0.1426**	0.2850**	0.8145**	0.7541**
R^2	0.2133	0.1535	0.2381	0.2078	0.1356	0.1045	0.3675	0.2666	0.3156	0.0466	0.0073	0.0082
R^2_α	0.4835	0.4370	0.5988	0.6836	0.8165	0.8305	0.6772	0.5537	0.6849	0.4267	0.1009	0.2341

Notes: a Except October-November 1918, May 1940-July 1945, and February 1953

b All models calculated with full model including seasonal time trend and temperature during different time lags; mid/high = middle class + elite.

* Significant ($p<0.05$), ** Significant ($p<0.01$)

α = overdisperion parameter, R^2 = ordinary correlation coefficient between observed and estimated dependent variable, overdisperion based $R^2\alpha = 1 - (\alpha / \alpha max)$, with αmax estimated from model with a constant term and overdispersion parameter only (see Miaou, 1996).

We observed during the period 1855-2006 an optimum temperature at which mortality generally is lowest. This was slightly different from the optimal temperature of 16.5° C that is observed in present-day epidemiological studies (Huynen et al. 2001). Over time, this optimal temperature increased from slightly below 15° C to around 17° C, which might be interpreted as an indication that the population is better adapted to temperatures that in the past had serious health consequences.

We were able to confirm the observations made by contemporaries during earlier heat waves that the relationship between temperature and mortality consists of direct and lagged effects. The fact that we could use daily temperature and mortality data allowed us to specify the lag periods that had the strongest effect on mortality. We showed that these lag effects were different for heat than for cold spells, and, unlike today, the effects of extreme heat were stronger for longer lag periods.

We also showed that children were by far the most vulnerable group when temperatures reached extremely high or low values. High summer mortality among children was primarily due to much higher rates of gastrointestinal diseases. These included not only deaths classified as ‘diarrhoea and enteritis’, but also a considerable number of deaths classified under the heading ‘*stuipen*’ (convulsions). Convulsions were usually the final and fatal effect of infection, often including dehydration resulting from gastrointestinal disturbances (Rombouts 1902:98,102). In normal years, mortality due to diarrhoea and enteritis and other acute gastro-intestinal diseases was already characterized by a strong summer peak.[12] The high mortality due to gastrointestinal diseases was above all a consequence of high proportions of artificially fed children. The quality of food stuffs, such as milk and bread porridge, deteriorated at high temperatures. Moreover, the quality of the water used to dilute the milk or to prepare other foodstuffs was extremely bad during periods of heat and drought. Thus the purity of feeding bottles and teats could not be guaranteed. In addition, insects responsible for the transmission of gastrointestinal diseases were present in much higher numbers. The fact that many children lived in high-density neighbourhoods and in poorly-ventilated houses, where the cooking and laundry was done in the room where the infant stayed during the daytime, further increased the death risks of young children. Over time, this age group became less and less sensitive to temperature fluctuations.

Whereas present-day studies consistently find a strong effect of extreme temperatures on the mortality levels of the elderly, this effect is hardly visible in our dataset. Only in the most recent period are there indications that people aged 75 plus

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[12] In Zeeland, for example, in 1910 and 1912 these acute gastro-intestinal diseases caused a doubling of the total number of deaths in July and August; in the exceptionally hot summer of 1911, these causes of death doubled the total death toll in July, increased the number of deaths in August by a factor of four, and the number in September by a factor of 2.5.

were experiencing an increase in mortality when temperatures reach extreme values. This relationship even appeared to be much weaker for our region of study than for the entire country.

The reduction in the effect of heat and cold on mortality from the period 1930-1954 onwards found in our study is confirmed by others. A study by McDowall (1981) focusing on England and Wales in the period 1841-1980 showed that there was a strong increase in excess winter mortality from the First World War until 1930, but that, especially from 1960 onwards, excess winter mortality has been declining. Carson et al. (2006) studied trends in seasonal and temperature-related mortality in London and found evidence of heat-related mortality in the earlier periods (1900-1910 and 1927-1937), but not in 1954-1964 and 1986-1996. The authors ascribed the reduction in susceptibility to developments in health care; improved nutrition, especially in the winter; better support services; and improved housing. For the Netherlands, Kunst, Looman, and Mackenbach (1991) studied the decline in winter excess mortality over the period 1953-88 and found that winter excess mortality in the period 1979-88 was considerably smaller than in the period 1953-57. The authors attributed this decline to the diminished exposure to cold because of the improvement in housing conditions, as well as improvements in clothing, footwear, working conditions (declining proportions working in agriculture), and transport. Also, it became evident from the strong decline in mortality in the last winter months of February and March that the delayed or more lasting effects of winter cold—such as depletion of fuel, degradation of food quality, impaired immunological defence, and increased socio-psychological stress—lost their importance because of rising standards of living (Kunst, Looman, and Mackenbach 1991).

Our study shows that the lowest social class was the most vulnerable group during temperature fluctuations. For other social classes, no clear effects of heat or cold were observed. The province of Zeeland was for a long time a rural area with a high proportion of (poor) unskilled farm workers, a group that is particularly vulnerable to indoor and outdoor exposure to cold due to bad housing, clothing, footwear, and working conditions. Kunst, Looman, and Mackenbach (1991) attributed the mortality decline that occurred later to improvements in these conditions. The results are in line with McDowell (1981), who found that winter excess mortality in England was higher among semi-skilled and unskilled workers than among other social classes.

Our findings partly confirm the observations made by contemporary doctors and statisticians. For example, the long lag periods that we found for heat were also suggested by studies of the paediatrician Cornelia de Lange and the medical doctor Heynsius van den Berg (1912). Both studied the effects of the 1911 heat wave, with De Lange looking at Amsterdam and Van den Berg focusing on all larger Dutch towns. De Lange observed that, while the increase in mortality generally followed the increase in temperature, in September, when the heat had already disappeared, the houses were still overheated and high mortality peaks could still be found. De Lange stressed the role of the indoor climate: even when the outdoor temperature had decreased, the temperature in the place where the child stayed could remain very high for quite some time. The situation was even more adverse when rooms were full of water vapour generated during laundry and cooking (De Lange 1913).

Our findings are also in line with those of the climatologist Van Everdingen (1907), who argued that there was no directly linear relation between fluctuations in temperature and in infant mortality, but that mortality increased only when a certain temperature limit was exceeded. Instead of using average temperatures, Van Everdingen compared mortality fluctuations with the number of days above a certain maximum temperature, and by taking a lag time into account. The idea that lasting and long-term effects of periods of high temperature are visible after several weeks of a child’s illness was suggested by other authors as well (Gezondheidscommissie 's-Gravenhage 1913:72-89). Given the prominent role that infant deaths played in the temperature-mortality relationship, it is clear that the reasons for the reduction in the effects of heat and cold lie primarily in the range of factors affecting infant mortality.

Our modelling still leaves several questions unanswered. We hardly studied the harvesting phenomenon, or the compensatory effect of heat waves brought about by declines in the numbers of deaths in subsequent weeks. We also did not model separately the effect of the length of the heat period, by, for example, using intervention models with dummies for heat periods of varying length. This type of analysis will make it possible to study the transition from a mortality regime in which only infants were severely affected by heat and cold, to one in which only the elderly were exposed to higher risks.

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