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HEAT WAVES AND COLD SPELLS AND THEIR EFFECT ON MORTALITY: AN ANALYSIS OF MICRO-DATA FOR THE NETHERLANDS IN THE NINETEENTH AND TWENTIETH CENTURIES

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INTRODUCTION

For many centuries, Hippocrates' thoughts on the role that weather conditions play on human health were a source of inspiration for physicians. Following the ideas that Hippocrates had formulated in his *On Airs, Waters, And Places*, physicians studied the ways in which the natural conditions of a country affected the appearance and virulence of diseases. When vital registration systems were introduced in Europe in the early nineteenth century and large-scale mortality data became available, empirical studies on the effect of periods of extreme heat or cold became possible for the first time. Doctors were now able to identify the negative health effects of heat and cold. For the Netherlands we can document the interest in this topic not only with statistical studies and official reports but also with literary sources and autobiographies, personal documents, newspaper articles and iconographic sources.

In 1868 summer temperatures in the Netherlands reached extremely high levels. With the help of locally collected data doctors studied the unusually strong increase in infant mortality (Gedeputeerde Staten Zeeland, 1869; Godefroi, 1869). A leading Dutch hygienist, Casper Pieter Pous Koolhaas (1831-1893), stated that in many places, in 1868 "more often than in many other summers, in the summer of this year an infant's body has been carried to the grave". The main reason for this extreme summer mortality was the kind of food supplied to children. Artificial feeding of children became even more difficult than it already was under normal circumstances. During hot weather, foods such as milk and bread porridge underwent "a slight change, and in this process start to decay [...]. To dilute the milk, or to prepare other foods or drinks, water is used, and if one considers how poor the water is in some places as a consequence of the heat and drought, then one has another reason for the harms that are caused in particular during hot summers by artificial feeding of infants". "The poorer the water used, and the sooner and broader the decay of the food, the higher too is the risk of uncleanness of the teats of the bottles in which one hands the food to the children." Pous Koolhaas argued that in hot summers the mortality of children of the poor increased more strongly than among children of the well-to-do. “It is among these families in whose dwellings, sooner than in the houses of the rich, the bad air manifests itself; in which, be it out of ignorance, negligence or frugality, more often bad or badly prepared food is given to the children, or what has been left from an earlier day [...]. Lack of discernment, unfamiliarity with the need for it also leads in these families to a less-than-required care for the complete purity of bottles and other utensils in which the child’s food is kept and which is so extremely important, particularly in hot weather. The milk that is bought by those people for whom spending a few more cents is a question of high importance will generally be poorer in quality than the one that can be supplied by those who wish to buy good stuff, even if that costs a bit more; and those who buy the bad and often-old milk, very frequently will have more trouble in trying to preserve it from decay.” (Pous Koolhaas, 1869).

The heat wave of 1911 drew even more attention than the one of 1868, as the latter’s death toll was indeed considerable. “Enormous loss of human lives”, in particular among infants, “a sad phenomenon, unparalleled in the statistics of recent years”, “a massacre” especially in the countryside and less so in the larger towns “with their good drinking water and controlled milk stations”—in these terms the Dutch press described the effect of the heat in November 1911 (De statistiek van den loop der bevolking, 1911). Medical doctors studied its consequences in detail, especially for infants. A survey had been set up in The Hague which followed for several years all children born in that city in 1908. The researchers had ample opportunity to pay attention to the effect of temperature on the sampled infants (Gezondheidscommissie 's-Gravenhage, 1913, 72-89). They stressed that the effect of heat periods was not only due to the rise in temperature as such but also depended on the duration of the heat period. The authors observed that mortality had increased not only for children aged one month or older but also in the first month of life. It appeared that after the extreme mortality in the summer months the death risks for infants in November and December were lower than in normal years. Detailed daily temperature and morbidity and mortality data were analyzed to examine the short- and long-term effects of temperature on illness and death. The authors were able to show that the number of days elapsing between the heat peak and the mortality peak shortened when the heat period kept up and temperatures rose further. Heynsius van den Berg (1912) found out through weekly data on numbers of infant deaths that the larger cities had withstood the summer of 1911 relatively well, a finding that he explained by the hygienic measures that had been taken there in the recent past. He observed no direct adverse effect of heat on infants; it was only after a series of days with extremely high temperatures that the situation for infants became unbearable. This was a consequence of the fact that outdoor as well as indoor temperatures reached very high levels. Data for Amsterdam also shows the effect of increases in indoor temperature (De Lange, 1913). In September 1911, when the heat had already disappeared but houses were still overheated, high mortality peaks could still be found. De Lange observed that the heat had less of an effect on children younger than one month. She credits this to very young children having relatively high rates of heat loss and the fact that many of these children were still being breastfed. Many deceased children had lived in single-room dwellings, and quite often the cooking and laundry was done in the room where the infant stayed during the daytime. Another problem was that in periods of extreme heat thirsty children received solid food or sour milk, and many infants were dressed with an excess of clothes (De Lange, 1913).

Contemporary observers also noticed the mortality-increasing effect of extreme winter temperatures. A case in point was the winter of 1890-1891, during which the agrarian population in particular, and among them the poor in the first place, suffered. An anonymous letter to the editor of a local newspaper (*Het Nieuwsblad*) on January 10th, 1891 described the situation in a region called the Hoeksche Waard, an island slightly north of the province of Zeeland. "The barren winter which quite unexpectedly holds sway with implacably harshness takes a heavy toll among the well-to-do, but how much more does it take out of our destitute human beings. […] Go and visit our poor and abide a few moments at the bedside of numbed old people; look at the chilly, shivering children, covered with rags, yearning for a nourishing meal or a warming fire. Look at those toddlers, sleeping under pieces of rugs, floor mats, shredded clothes, or other things that a caring parental hand has been able to find as cover; see with your own eyes that in our midst people can be found who are less well-off than animals in the cowshed; people who do not have a bed, sometimes no straw, to lay their numbed limbs down to rest, who are lacking everything except distressing poverty, deep misery." (Perneel, 2000, 249).

After almost a century, in this paper we study again the effect on mortality of the extreme Dutch winters and summers of the nineteenth and twentieth centuries. We focus on those topics which already attracted the attention of medical doctors at the time: Were some age groups more vulnerable than others? Were there social classes that had to endure the effects of heat and cold more than other groups? Were there indeed short-term and longer-lasting effects of heat and cold? In contrast to the nineteenth-century studies, we combine detailed mortality and temperature data with advanced time-series methods to shed new light on the effects that heat waves and cold spells had on mortality in the past. Questions such as these have only received limited attention by historians. Medical doctors and public health specialists had lost their interest in the temperature-mortality link after WWI[2], for various reasons. One is that water- and food-borne and air-borne infectious diseases, the spread of which was more sensitive to respectively extremely high and extremely low temperatures, lost their importance. Deaths among infants and children, the group most vulnerable to high and low temperatures, became rare occurrences. And, very important, economic and technological developments—improved housing, better working conditions, reduced outdoor employment, better transport, to name only a few—reduced exposure to and the negative consequences of extreme temperatures. This all changed when in August 2003 Western Europe experienced an unprecedented hot summer (probably the hottest in Europe since 1500; see Luterbacher, Dietrich, Xoplaki, Grosjean, & Wanner, 2004), with deadly consequences for the population. Detailed analyses of the excess mortality related to that heat wave were published for many European countries (for France, see e. g. Rey, Fouillet, Jougla, & Hémon, 2007). Haines *et al.* (2006) argued that "climatologists now consider it very likely that changes in climate have doubled the risk of a heat wave such as that experienced in 2003". We will attempt to show here that the relation between extreme weather conditions and mortality and the changes therein over time are an interesting research topic for historians too. How societies coped with environmental shocks such as extremely high temperatures and whether or not they were able to restrict their effects on mortality provides us with a valuable measure of societal development (Galloway, 1994). Studying the differences in vulnerability to this environmental stress by social class, age and sex gives us information on the conditions—food, shelter, clothing—under which these groups lived and on the way these conditions changed over time (Bengtsson, 2004). This is nowhere better illustrated than in Eric Klinenberg's *Heat wave: a social autopsy of disaster in Chicago* (Klinenberg, 2002).

Compared with a recently published study in which we also analyzed the changing temperature-mortality link, the present study encompasses data for four provinces instead of the single one that was the topic of our earlier paper (Ekamper, Van Poppel, Van Duin, & Garssen, 2009). This not only allows us to reach firmer conclusions, it also makes it possible to compare regions that differ in their microclimatological environment.

THE TEMPERATURE-MORTALITY LINK AS TOPIC FOR HISTORIANS

There have been few quantitative assessments of excess mortality during heat waves or cold spells for historical populations, let alone studies in which the vulnerability of specific groups was analyzed. Historical studies of the link between extreme weather conditions 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 distinction by sex or age, and often only on a monthly basis, whereas temperature data tend to be monthly averages (see e. g. Galloway, 1985; Galloway, 1986; Galloway, 1988; 1994; Landers, 1986; McDowall, 1981). An important drawback of a monthly aggregation of mortality data is that it makes it almost impossible to properly identify the effects of extreme heat or cold on mortality. Deaths caused by extreme heat, for example, appear to occur at very short lags (0-1 days) and it is therefore highly likely that an effect of heat-related mortality will be attenuated even in a weekly-aggregated analysis (Carson, Hajat, Armstrong, & Wilkinson, 2006). Historians rarely have access to information on daily numbers of deaths and daily temperature data, and where that is the case these records are collected only for small communities and restricted time periods.

The number of studies in which the relation between extreme weather conditions and mortality is studied over a long period of time with adequate methods and on the basis of comparable data is extremely limited. Contemporary epidemiological studies rarely cover a period long enough to encompass major economic, demographic or epidemiological transitions (Carson *et al.*, 2006). There is not a single study in which advanced time-series methods have been used to study mortality displacement during heat waves and cold spells for historical populations. Recently, Rau (2007, 13-14) noted that "surprisingly, there is not much literature in the field of seasonal mortality on the 'classical' social mortality determinants such as income, deprivation, wealth, marital status, education, occupation". He also noted that "most of these analyses […] studied the same country (UK) using similar methods based on ecological data". Rau was referring to the present-day situation, but his conclusion applies even more to the historical study of the effect of extreme weather conditions. Although during heat waves and cold spells contemporaries often referred to the effects that extreme weather had on the poor in particular, there is hardly an empirical study focusing on this aspect.

In past decades historical databases with more detailed information on deaths have become available for a number of countries. This paper uses data relating to four of the eleven provinces of the Netherlands, covering a period of 100 years and allowing us to study the effect of extreme temperatures separately by age, sex and social class. We relate these mortality data to series of standardized, location-specific daily temperature measurements, and in doing so we make use of sophisticated statistical methods. 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 (lasting until around 1875) to a regime in which infectious diseases disappeared almost completely and degenerative diseases became the most important cause of death. This transition of the cause-of-death pattern was accompanied by a changing age profile of death, in which no longer infants but the highest age groups accounted for the majority of deaths.

The period that we study is also an interesting one 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. As we are able to compare regions with different levels of economic development we have an excellent opportunity to find out how vulnerability to extreme circumstances changed over time and varied by region.

Of course our dataset also has some drawbacks. Periods of extreme heat and extreme cold are scarce in the Netherlands, with maximum temperatures only sporadically exceeding 27°C and minimum temperatures rarely dropping below –10°C. As a consequence, the variation in temperature-related mortality is small by international standards (Healy, 2003; Keatinge *et al.*, 1997; Keatinge *et al.*, 2000; McKee, 1989). On the other hand, studies have documented that in countries with harsh climatic conditions during winter, winter excess mortality is lower than in countries with relatively warm or moderate climates, and this same mechanism applies to the excess mortality during summer. This "seasonality paradox" (Gemmell, McLoone, Boddy, Dickinson, & Watt, 2000), resulting from the fact that the population is not accustomed to protecting itself adequately from uncommon temperatures, might have led to strong effects even in a country with a moderate climate like the Netherlands.

Unfortunately, we have no information on climatic conditions other than temperature which might have an effect on mortality, such as humidity, wind speed or wind direction. Nor do we have information on temperature-related variables such as air pollution and influenza, which might have played a role in (changes in) weather-related excess mortality.

MECHANISMS IN WEATHER-RELATED MORTALITY

A large number of studies present overviews of the factors that account for an increase in mortality due to cold or heat in contemporary societies. As Keatinge and Donaldson (2004, 1094-1095) have made clear, few of the excess deaths during cold are due to the body simply cooling until vital organs such as the heart cease to function, and few heat-related deaths are due to hyperthermia, overheating of the body. Cold-related deaths are mainly caused by coronary and cerebral thrombosis and respiratory diseases, whereas the same thromboses account for most heat-related deaths. The precise effects of extreme heat or cold depend not on temperature as such alone[3] but also on specific conditions in which the temperature decline or rise took place and on other climatic conditions.

The effects of cold and heat may consist of a more or less *instantaneous effect* and a more *delayed effect*. Temperature falls in winter are closely followed by increased mortality, with characteristic time courses for different causes of death. For heat periods too, immediate effects (such as acute myocardial infarction) as well as long lag times might be distinguished. 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 during which the temperature is extreme (Huynen, Martens, Schram, Weijenberg, & Kunst, 2001). Main heat effects are usually visible on the current day or may last another day or two (Pattenden, Nikiforov, & Armstrong, 2003). *Compensatory effects on mortality* might be registered when longer time periods are studied. The number of deaths caused by heat waves is often assumed to be compensated for by a fall in number 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 "harvesting" effect (Huynen *et al.*, 2001). However, no general agreement exists among scientists on the length of the period over which harvesting effects can be expected, which vary from a few days or weeks in the short term to several months or even years in the longer run (Toulemon & Barbieri, 2008). The effects of heat and cold might also be contingent on the *sudden occurrence of a change in temperature*. Such effects depend on whether populations have had the chance to adapt to extreme weather conditions (Ballester, Michelozzi, & Iniguez, 2003). Effects of outdoor air temperature might be *modified by other weather conditions*, such as high humidity and strong air flow (Gill, Davies, Gill, & Beevers, 1988). A study on daily variation in mortality in relation to temperature and two wind-chill indices for the Netherlands (1979-1987) showed that hazardous weather situations could be identified almost as accurately by temperature as by an index that also included wind-chill (Kunst, Groenhof, & Mackenbach, 1994). Effects of high and low temperatures also depend 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 remarkably effectively over time. This applies to cold as well as to hot regions (Keatinge *et al.*, 2000). Countries with the mildest winter climates exhibit the highest effect in winter mortality (Healy, 2003). Breschi and Livi-Bacci (1994) and Oris *et al.* (2004, 392-393) showed that winter peaks in mortality among infants were more common in climates with mild winters than in harsh climates where the population had a high capacity for adaptation: thus in temperate regions winter is a more dangerous and impacting period than summer, although clothes, heating and good housing could reduce its effects.

It is important to stress that the temperature-mortality link might be due to *mechanisms other than the direct effects of exposure* of the human body to extreme temperatures. In particular for historical populations, these indirect effects on mortality cannot be neglected. We mention here two of these mechanisms. Extreme weather has a direct effect on biological processes that are crucial to man's survival, such as the growth of foodplants and animals, and on the physical environment, such as flooding and storms. These direct effects could lead to second-order effects on mortality (Michaelowa, 2001). Relevant is also the link between temperature and the incidence and virulence of infectious diseases, the most important cause of death until the first decades of the twentieth century. Temperature and rainfall affect the mobility and strength of pathogenic micro-organisms and those of insects and animals that carry them. Where sanitation was virtually unknown and water supplies subject to contamination, warm summers promoted the spread of infectious diseases through increased proliferation of animal, insect and bacterial vectors (Galloway, 1994). Cases in point are malaria, diarrhea and other gastric conditions, the latter particularly affecting those children who had lost the protection of the mother's milk (Oris *et al.*, 2004).

In studies dealing with present-day effects of extreme temperatures on mortality the question often is whether there are specific groups whose health is more affected by extreme heat or cold than others. Usually the focus lies on gender and/or specific age groups, and physiological factors are used to explain differences. Significant variations in effects of heat and cold according to age have been related to variations in thermoregulatory function and appreciation of cold and heat with age. This is considered the main reason why the elderly are disproportionally affected by extreme weather conditions (Hajat, Kovats, & Lachowycz, 2007). There is no evidence in present-day studies of excess mortality attributable to heat waves in children (Kovats & Kristie, 2006), and only rarely is mention made of the effect of extreme cold on the death risks for this age group. The determination of which gender is more susceptible to weather fluctuations is much in dispute. In studies of England, Wales and France women had higher heat-related mortality, reflecting adverse effects of menopause on thermoregulation (Hajat *et al.*, 2007; Rey *et al.*, 2007). For cold-related mortality, gender differences were not significant (Keatinge *et al.*, 1997).

Relatively little present-day research has examined variation in temperature vulnerability by socioeconomic position, and the few existing studies often present conflicting results. O'Neill *et al.* (O'Neill, Zanobetti, & Schwartz, 2003) observed stronger cold and heat effects among the less-educated in most of the seven US cities they studied. Such an effect was not found in a Spanish study (Borrell *et al.*, 2006). Naughton *et al.* (2002) found increased risk of heat-related death during the 1995 Chicago heat wave among low-income residents, whereas Kaiser *et al.* (2007) found the same effect among the lower educated. McDowall (1981) observed higher winter excess mortality in England during the 1959-1972 period among semi-skilled and unskilled workers than among other social classes. Donaldson and Keatinge (2003) observed for 1998-2000 in England and Wales that cold-related mortality in men of working age was low for unskilled occupations but high among 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. Other authors have argued that unacceptable working conditions during *high* temperature periods can lead to increased mortality in lower social classes. Rau (2007, 127-162) studied individual-level data for Denmark for 1980-1998, using a variety of socioeconomic indicators. He did not observe a connection between excess winter mortality among people aged 65 years or older and factors such as educational level, wealth and housing conditions. Area studies give conflicting results too. A study for the 1993-2003 period in the UK (Hajat *et al.*, 2007) observed very little difference in heat effects according to level of deprivation of the neighborhood and no link between cold and deprivation. Results of a study of the French 2003 heat wave however point to the most deprived populations being more vulnerable to heat waves (Rey *et al.*, 2009). It remains to be seen whether in the nineteenth and early twentieth centuries such a difference in vulnerability also can be observed.

SETTING, DATA AND METHODS

Study regions

Nationwide and compulsory birth and death registration according to the rules laid out in the Napoleonic Code was introduced in the Netherlands in 1811, at the time of incorporation of the Netherlands into the French Empire. In recent decades, dozens of staff and volunteers in Dutch provincial archives have started to enter death records into a database within the framework of projects called ISIS and GENLIAS. The purpose of these projects is to build a database with genealogical information on all marriages, deaths and births taking place in the Netherlands from the introduction of the vital registration system (1811) up to when such data were not yet in the public domain. Death records enter the public domain after 50 years. We were able to use data for four of the eleven provinces of the Netherlands: Zeeland, Drenthe, Groningen and Gelderland. These provinces were selected because entry of death certificates has been completed for the whole of the province and because the information entered in the database includes information on sex, age and occupation of the deceased[4]. Figure 1 gives an overview of the location of the selected provinces.

Fig. 1 *Map of the Selected Dutch Provinces around 1920*

The four provinces each have their own particular ecological, social and economic structure. Gelderland is located in the central eastern part of the country, extending from the German border westward to the former Zuyder Zee. In the northwest the hill plateau of the Veluwe was a wasteland covered with heath and some woods, ill-adapted for cultivation and of little economic value except for some wood-cutting and paper mills. The fertile marshy area of the Betuwe between the Rhine and the Waal supported orchards, market gardening and mixed farming. The southwestern section was a long, narrow westward extension along the Rhine river with brickyards and dairy farming. Some textile works were located to the east. Small regional marketplaces and several larger towns such as Arnhem and Nijmegen hosted industrial activities and administrative services. Farms in Gelderland were relatively small, the infrastructure less well-developed, and the productivity of land and labor lower than that of the coastal provinces.

Drenthe is located in the northern part of the country and shares an eastern border with Germany. The soil consists almost entirely of sand and gravel, and was for a long time covered with bleak moorland, patches of wood, and fen. Cultivation of buckwheat and peat-digging took place on the barren heaths and sodden fens found on the sand grounds, where sheep and cattle were reared and forest cultivated. In connection with the cultivation of potatoes, factories were founded for making spirits, straw paper, etc. The people of Drenthe have had a long history of poverty. The poor agricultural soil did not always yield enough to prevent farmers from starving. People often lived in turf huts and supplemented their incomes through peat-cutting. Besides that, a large penal establishment was erected in the mid-nineteenth century to which drunkards and beggars from all over the country were sent. Owing to its geographical isolation, the development of the province remained behind that of all other Dutch provinces. There were few urban centers of any importance and population density was rather low.

Zeeland forms the southwestern part of the coastal zone and consists of a strip of the Flanders mainland, bordering Belgium and six former islands, all of them now connected to each other or to the inland provinces by dams and bridges. Much of Zeeland was below sea level and protected by a system of river and sea dikes. For a long time, Zeeland was a rural area with the towns of Middelburg and Vlissingen as administrative and industrial centers. Grain farming on the sea clay was the chief economic activity (60 per cent of the labor force was involved in agriculture). Part of the population was active in the fishing industry. In the second half of the nineteenth century agricultural modernization was eroding the position of farm laborers. The economy of the region started to change after 1900 with industrialization (Priester, 1998; Wintle, 1985).

Groningen, situated in the extreme north-east of the Netherlands, can be roughly divided into two regions: a northern area of clay soils and a southern one of sand and peat. The peat districts became an area of important industrial development in the second half of the nineteenth century. A common feature of the agriculture of both areas was the high degree of commercialization.

Mortality levels in the four provinces differed considerably. Whereas Zeeland, like other Dutch coastal and low-lying areas, was characterized by very high mortality until late in the nineteenth century—particularly among infants, reaching levels of 350 deaths before age 1 per thousand live births—Drenthe, Groningen and Gelderland were doing much better. As Table 1 shows, the expectation of life at birth in Zeeland was much lower than elsewhere until the middle of the nineteenth century, and it was only in the century's latter decades that the province reached higher values of life expectancy.

Tab. 1 *Expectation of Life at Birth, by Sex, Period and Province*

	Drenthe		Gelderland		Groningen		Zeeland	
Period	M	F	M	F	M	F	M	F
1850-59	41.2	41.4	41.9	43.4	39.1	41.1	30.1	31.8
1901-02	49.5	50.2	50.2	52.4	50.4	52.9	52.0	55.4
1956-60	72.3	75.0	71.8	74.6	71.8	75.5	72.6	75.2

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.

Together, the four regions cover a large portion of the economic, demographic and cultural landscape of nineteenth-century Netherlands. The climatological conditions in the four regions differed slightly. The average annual temperature in Zeeland was usually slightly higher than elsewhere in the country, due to its coastal location and a higher number of hours of sunshine. In particular, the average minimum temperature was higher in Zeeland than in other parts of the Netherlands, with temperatures rarely dropping below –10°C, especially in the westernmost regions. In Gelderland however, and even more so in Drenthe and Groningen, minimum and maximum temperatures were more extreme. The average number of frost days (below freezing point) in the northeastern provinces was much higher than in Gelderland and Zeeland (Heijboer & Nellestijn, 2002).

Weather and mortality data

Temperature readings were taken at different weather stations in the Netherlands starting in the early 1850s. At the beginning of 2000, the Royal Netherlands Meteorological Institute (KNMI) started research on historical instrumental observations of the weather in the Netherlands within the framework of the E.C. Climatological Research Programme, HISKLIM (HIStorical CLIMate). The objective of HISKLIM is to make historical meteorological observations from Dutch-language sources available in a digitized format (see KNMI, 2009).

Weather measurements in the nineteenth century were done using self-recording apparatus with a moderate degree of reliability. Due to changes in the number of readings, the time at which the readings took place, measuring position, measuring instruments, etc., the climate time series are not homogeneous[5]. To increase their usefulness, the data for daily mean temperature and maximum and minimum temperatures have to be homogenized. Various procedures have been developed to calculate the temperature for every hour of a given day from a small number of at least two regular readings on the same day (Van der Hoeven, 1992; Van Engelen & Geurts, 1983). We used a slightly adapted version of the method of Van Engelen & Geurts (see Van Duin, 2008) to calculate homogeneous mean daily temperature and maximum and minimum temperatures from 1854 to 1950. Given the differences in climatological conditions between the four provinces we decided not to use one single temperature series for all four regions but to apply region-specific measurements. For Zeeland we used data from the Vlissingen weather station, for Gelderland those of the Utrecht/De Bilt weather station, and for Drenthe and Groningen those of the Groningen/Eelde weather station[6].The distance between the weather stations and the areas for which the weather measurements were considered indicative was modest. For Zeeland the largest distance between the weather station and any of the province's municipalities for which we had mortality data was 45.9 km, for Gelderland it was 109.2 and 106.7 km, and for Drenthe and Groningen 63.0 respectively 56.8 km[7].

For each of the three stations we calculated a series of indicators of (extreme) temperature conditions. The average daily 24-hour temperature was rather stable over time but varied between the regions/stations, with Zeeland registering slightly higher temperatures than Drenthe/Groningen and Gelderland but with much more frequent extremes in the latter two provinces. Both the number of tropical days (maximum temperature above 30°C) and the number of ice days (maximum temperature below 0°C) were much higher in Drenthe/Groningen and Gelderland. Mean heat and cold values showed a comparable pattern. The Netherlands Royal Meteorological Institute classifies winters and summers by using annual cold (or Hellmann) values[8] and heat values[9]. The Hellmann value was much lower in Zeeland and the mean heat value was highest in Gelderland, followed by Zeeland and Drenthe/Groningen.

According to the official definition by the Netherlands Royal Meteorological Institute, a heat wave is defined as a period of at least five days, each with a maximum temperature of at least 25°C (called summer days), including at least three days with a maximum temperature of at least 30°C (called tropical days), measured at the De Bilt station located in the centre of the Netherlands. Applying this definition to the weather stations in our study, there were only four heat waves in Zeeland in the 1855-1950 period against 18 in Drenthe/Groningen and 27 in Gelderland. A cold spell is a consecutive series of at least five ice days (maximum temperature below 0°C) including at least three days with severe frost (maximum temperature below –10°C), thus according to this definition there were eight cold spells in Zeeland against 31 in Drenthe/Groningen and 33 in Gelderland.

Mortality data for the four provinces are available for the 1812-1950 period. We recoded ages at death into age groups and occupation/social class of the deceased, their parents and spouse when applicable. Ages at death were classified into the following groups: stillbirth, first-year mortality (age at death less than 1 year), deaths at ages 1-4, 5-19, 20-49, 50-74 and ages 75 and older.

We classified all occupations of deceased persons, their spouses and parents in a social class system, based on a recently developed coding scheme called HISCO (*Historical International Standard Classification of Occupations*) (Van Leeuwen, Maas, & Miles, 2002). HISCO translates occupational descriptions into a common code, compatible with the International Labour Organization'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 potential to influence one's "life chances" through control of (scarce) resources and is based on economic factors (like self-employment, skill and authority) and cultural resources (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[10]. We denote these groups as the elite, middle class, skilled workers, semi-skilled workers and 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. Given the small numbers we grouped the elite with the middle class together in one group. Many of the deceased could not be placed in a category, as they were not yet or no longer economically active at the time of their death.

Descriptive statistics for the mortality and temperature variables by 25-year period and province are presented in Table A-1 of the Appendix. The total number of deaths in the database was 1,843,301, ranging from 521,450 in the 1855-1879 period to 367,243 for 1930-1955. Around 18 per cent of all deaths concerned infant mortality (below the age of 1 year), and around 42 per cent persons aged 50 or older. The percentage of infant deaths was much higher in Zeeland. The distribution of deaths by age group shows a shift from younger to older age groups. In the first two periods around 23 per cent of all deaths concerned mortality below age 1, dropping in the most recent period to less than 8 per cent. The share of the oldest age groups, 50 years and older, increased from 29 to almost 64 per cent. The distribution by social class shows that a large majority of the deaths belonged in the laboring classes—unskilled and semi-skilled workers in and outside agriculture together constituted around 33 per cent of all deaths, and skilled workers around 10 per cent. Nearly 12 per cent of the deaths happened in farming families. Upper and middle classes made up 11 per cent of the total. In all provinces the percentage of deaths of unskilled and semi-skilled workers in and outside agriculture decreased considerably over time. This was also the case with farmers. At the same time there was, particularly in the most recent period, an enormous increase in the number of deaths with social class unknown (that is, either unknown or no occupation given, particularly among women).

Method

We use statistical modeling to study the link between extreme temperatures and mortality. The approach we adopt is similar to the one used in two recent studies of the impact of heat waves and cold spells on mortality in the Netherlands during the 1979-1997 period (Huynen *et al.*, 2001) and in the Dutch province of Zeeland for 1855-2006 (Ekamper *et al.*, 2009). With regression analysis we can fit the relationship between a dependent variable (daily number of deaths) and one or more independent variables (like daily average temperatures, long-term time trend and seasonal pattern). The resulting estimated regression model describes the relationship between the dependent variable and the independent variables in terms of regression coefficients. The regression coefficients indicate the effect of the single independent variable on the dependent variable. Several techniques for carrying out statistical regression analysis have been developed. Poisson regression fits models with a dependent variable that denotes the number of occurrences (counts) of an event. Since we are dealing with count data (number of deaths) we thus need to use a Poisson regression. Poisson regression assumes the mean of the dependent variable (mean number of deaths) to be equal to the variance of that variable. However, in our case the observed variance of the dependent variables (total numbers of deaths, number of deaths in selected age groups and social classes) is generally greater than their mean. This is known as overdispersion. To account for overdispersion of our dependent variables we need to use a special case of Poisson regression, negative binomial regression (see Cameron & Trivedi, 1998; Hilbe, 2007; McCullagh & Nelder, 1989).

In our analyses the daily total numbers of deaths, as well as the number of deaths in selected age groups and social classes, were thus related to the daily average temperatures using negative binomial regression models for the whole dataset (1 January 1855 to 31 December 1950) and subsets (25-year periods, heat waves and cold spells), controlling for long-term time trend and seasonal pattern[11]. In the analyses the winter period includes the coldest months in the Netherlands: December, January and February. As many studies have shown, seasonality is ever-changing over time both in the Netherlands (Kunst, Looman, & Mackenbach, 1991) and other countries (see e.g. Eilers, Gampe, Marx, & Rau, 2008; Lerchl, 1998; Marcuzzi & Tasso, 1992; Seretakis *et al.*, 1997). To account for the varying cyclical seasonal pattern in the regression models, 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 $t=1,\dots,T$ 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 e.g. population size and structure and socioeconomic and health care conditions was included as a restricted 7 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 7 knots cubic smoothing splines of the annual f and g estimates of the Gampe-Rau model. The resulting estimated varying cyclical seasonal pattern over the years is included as one of the independent variables in the negative binomial regression model. The varying cyclical seasonal pattern was estimated for all four provinces separately.

Both extremes of temperature have adverse effects on health, which causes complications in modeling. Most researchers have dealt with this problem by concentrating only upon either cold effects or heat effects; we prefer to model heat and cold simultaneously by using information on the V-like link between mortality and temperature. To account for this link (see e.g. Huynen *et al.*, 2001), average daily temperatures within the model were measured by two complementary variables, heat (0 if average temperature was lower than the optimum value, otherwise average temperature minus optimum value) and cold (0 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.* for the Netherlands, 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:

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

where y_i (dependent) is the number of deaths on day i, h_i (heat) is the average value for heat on day i, $h_{i-1,i-2}$ to $h_{i-15,i-30}$ the average heat values for lag times 1-2 to 15-30, c_i (cold) the average heat values for cold on day *i*, $c_{i-1,i-2}$ to $c_{i-15,i-30}$ the average cold values for lag times 1-2 to 15-30, and s_i (seasonality) 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 and the average daily number of deaths by sex, age group in years (<1, 1-4, 5-19, 20-49, 50-74, and 75 or older) and social class (unskilled workers, semi-skilled workers, skilled workers, farmers, and middle class and elite) in years with heat waves and cold spells. Additionally, negative binomial regression analyses with respect to average daily total number of deaths were applied to shorter (25-year interval) time periods (1855-1879, 1880-1904, 1905-1929 and 1930-1950) during all summers and winters per period for total mortality and for farmers and unskilled workers.

RESULTS

We start with a descriptive analysis of the effect that periods of extreme heat and cold could have on mortality. Four examples are given to get an idea of these effects for specific years. To that end we selected four years with extreme heat and four winters with extreme cold. The Netherlands Royal Meteorological Institute classifies winters and summers by using annual cold (or Hellmann) values and heat values calculated from the measurements of the Utrecht station (see previous section). To be able to select years with extreme heat and cold in the same year in all four provinces we calculated the annual heat and cold values for all three stations. However, the ranking of the years is different per province, therefore we selected four summers and four winters that on average ranked the highest when combining the rankings of the three stations[12]. We selected the extreme-heat summers of 1868 (average ranking 2nd), 1884 (4th), 1911 (3rd) and 1947 (1st), and the extreme-cold winters of 1854-55 (2nd), 1890-91 (3rd), 1928-29 (4th) and 1946-47 (1st). Table 2 gives some information about the selected years. In all stations the summer of 1947 had by far the highest heat value (the Utrecht station counting as many as four heat waves), followed by the summer of 1911 (the Utrecht station being an exception). The winter period of 1946-1947 was by far the coldest at all stations, its cold value higher than any other year.

Figure 2 shows the daily mortality ratio (the observed number of deaths in a day divided by the average number of deaths per day in that year) and the average 24-hour temperature in years characterized by heat waves, whereas Figure 3 does the same for years characterized by cold spells. For reasons of readability we chose to present the data for the Gelderland province only.

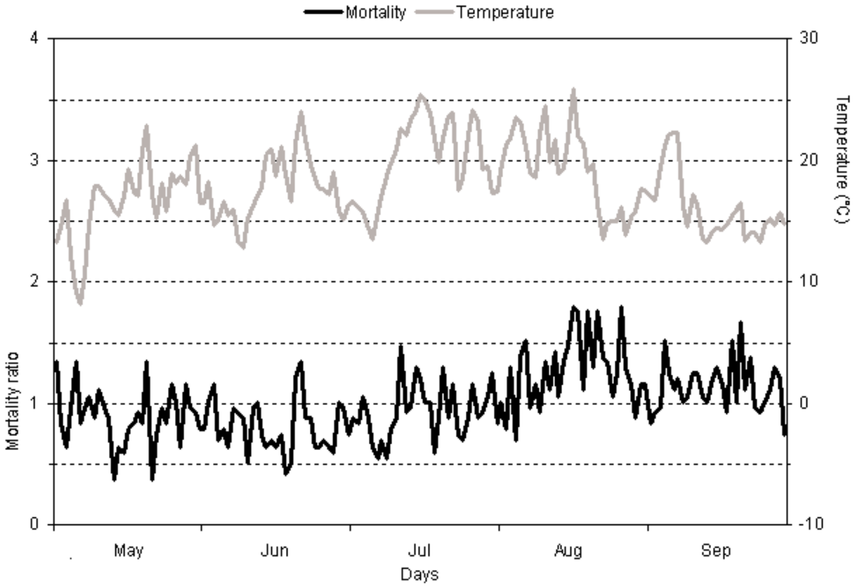
As shown in several studies, the effects of extreme heat or cold may consist of a more or less instantaneous effect and a more delayed effect. In 1911 for example, in Gelderland after a first heat wave starting around July 20 mortality started to increase after one week. Temperature peaked around July 29 and again several days during August and September. Average temperatures for lag days 7-14 and 15-30 show patterns that are more or less in line with the mortality pattern. Yet there were very strong differences between provinces and between specific years in the effect that summers with

Tab. 2 *Number and Duration of Heat Waves and Cold Spells, Heat and Cold Values, Number of Summer Days, Tropical Days, Ice Days and Days with Minimum below -10°C by Weather Station for Selected Summers and Winters*

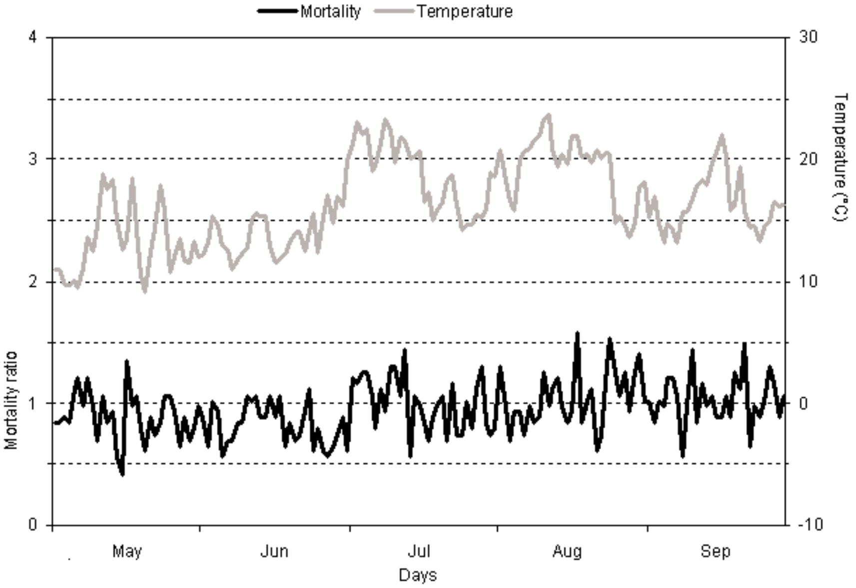
	Drenthe/Groningen					Utrecht					Vlissingen				
	Heat waves		Heat	Sum.	Trop.	Heat waves		Heat	Sum.	Trop.	Heat waves		Heat	Sum.	Trop.
Period	N	days	value	days	days	N	days	value	days	days	N	days	value	days	days
1868	0	0	97.9	25	2	1	14	208.2	43	11	0	0	142.9	28	2
1884	0	0	22.7	10	0	0	0	129.0	32	0	0	0	137.8	22	2
1911	2	17	123.8	32	12	2	19	135.0	42	12	1	7	166.8	31	11
1947	2	14	180.1	40	12	4	38	221.3	57	18	1	11	179.8	33	4
	Drenthe/Groningen					Utrecht					Vlissingen				
	Cold spells		Cold	Ice	10°C	Cold spells		Cold	Ice	10°C	Cold spells		Cold	Ice	10°C
	N	days	value	days	days	N	days	value	days	days	N	days	value	days	days
1854-55	2	28	266.2	38	15	3	33	260.7	33	18	1	11	162.1	24	6
1890-91	1	28	240.1	45	7	3	27	256.2	36	12	1	13	182.3	30	3
1928-29	1	11	270.1	34	16	0	0	227.1	26	15	1	11	139.5	24	5
1946-47	2	39	405.6	52	17	3	40	342.8	46	21	0	0	220.8	40	1

Fig. 2 *Daily Mortality Ratio and Average 24-Hour Temperature (°C) in the Dutch Province of Gelderland in the Summers of 1868, 1884, 1911 and 1947*

(a) Summer 1868

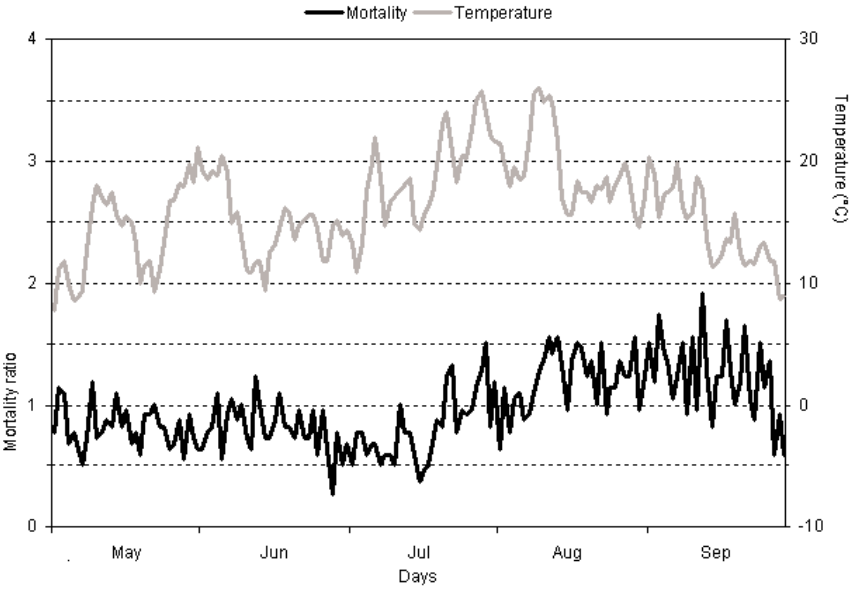


(b) Summer 1884

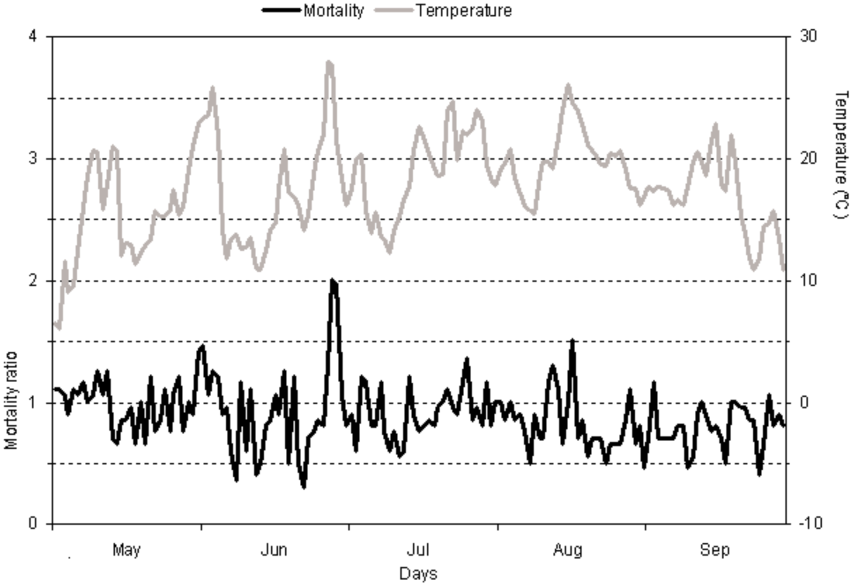


Mortality ratio = observed number of deaths per day divided by average number of deaths in the same year

(c) Summer 1911



(d) Summer 1947



Mortality ratio = observed number of deaths per day divided by average number of deaths in the same year

heat waves had on mortality. In all four provinces the summer of 1868 had immediate and delayed effects on mortality, with mortality ratios reaching values around 2 (that is, a doubling of the expected number of deaths). The summer of 1884 had a very strong and long-lasting effect on mortality in Zeeland but left the mortality patterns in Gelderland, Groningen and Drenthe almost unaffected. The famous summer of 1911 again had an effect mainly on mortality ratios in Zeeland but almost no effect was observed in the other provinces. Finally, the summer of 1947, the second hottest since registration of time weather data started in the Netherlands, left no trace on the provinces' mortality ratio.

Figure 3 shows mortality and temperature in the coldest winters (December to February) for 1855-1950. Again, here we find rather different reactions per year and province. For example, during the winter of 1854-1855 strong effects were found in Zeeland, Groningen and Gelderland with doubled mortality ratios but only a weak reaction followed the period of extreme cold in Drenthe. During the winter of 1890-1891, mortality ratios in Zeeland again responded directly to the temperature decrease, as did those in Gelderland to a lesser degree, but in Drenthe and Groningen no reaction was found whatsoever. The winter of 1928-1929 did lead to a strong increase in mortality in Gelderland, Groningen and Drenthe, experiencing more than twice the normal expected numbers of deaths per day. The winter of 1946-1947 did not provoke outspoken mortality peaks in any of the four provinces.

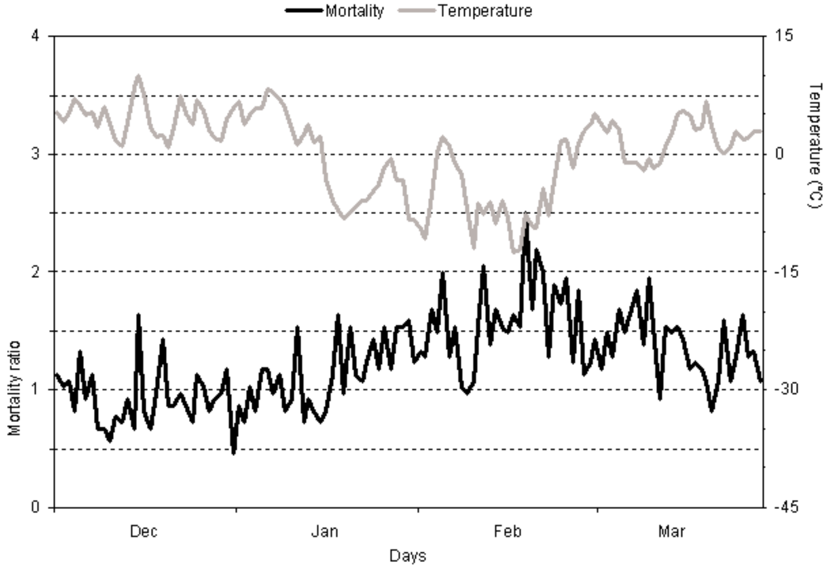
Figures such as those presented above leave a lot of room for different interpretations of the relationship between temperature and mortality. They cannot take the effect of seasonality into account just like that of above- or below-optimal temperatures, nor do they allow reckoning with the effect of long-term trends in numbers of deaths or other relevant factors such as the changing age distribution of deaths. For that reason we now turn to multivariate statistical models, which offer a solution for at least some of these problems. They allow us to take a real step forward compared to the mainly descriptive statistical analyses presented by the contemporary medical doctors and statisticians.

The results of the regression model explained in the previous section are presented in Tables A-2, A-3 and A-4 of the Appendix. Table A-2 presents the regression coefficients of the model applied to all years with either a heat wave or a cold spell (as defined in the previous section), Tables A-3 and A-4 do the same for all summers and winters. In Table A-2 the model was applied to total mortality (total number of deaths per day) and to number of deaths by sex, age group and social class. All models were calculated with the full model including seasonal time trend.

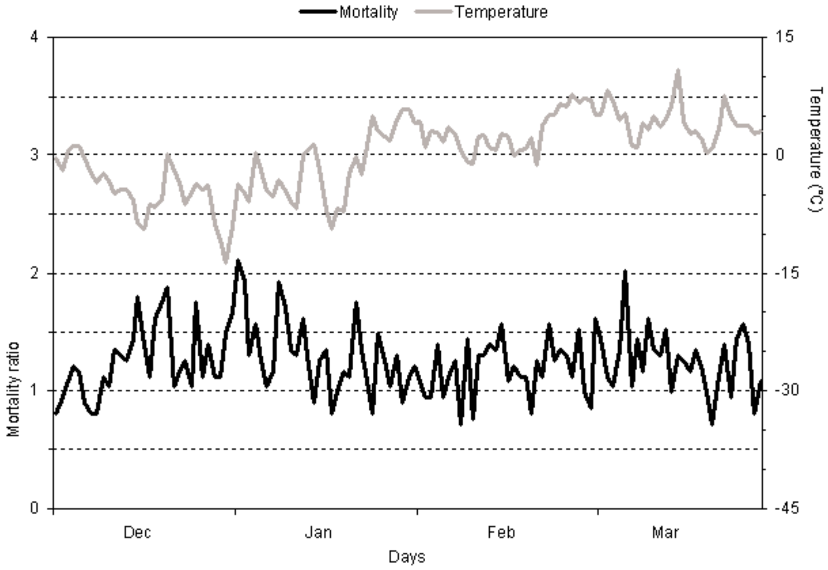
The general relationship between mortality and temperature can be judged by the ordinary r^2 and, in case of overdispersion, by the overdispersion-based r^2[13]. The model fits the Zeeland data much better than that for Gelderland and Groningen and even more so than that for Drenthe. Furthermore, models fit the temperature-mortality link much better among the elderly than among infants, children and adults, but Zeeland is an exception to this rule, as here the models reach their highest values of r^2 for infants.

Fig. 3 *Daily Mortality Ratio and Average 24-Hour Temperature (°C) in the Dutch Province of Gelderland in the Winters of 1854-1855, 1890-1891, 1928-1929 and 1946-1947*

(a) Winter 1854-55

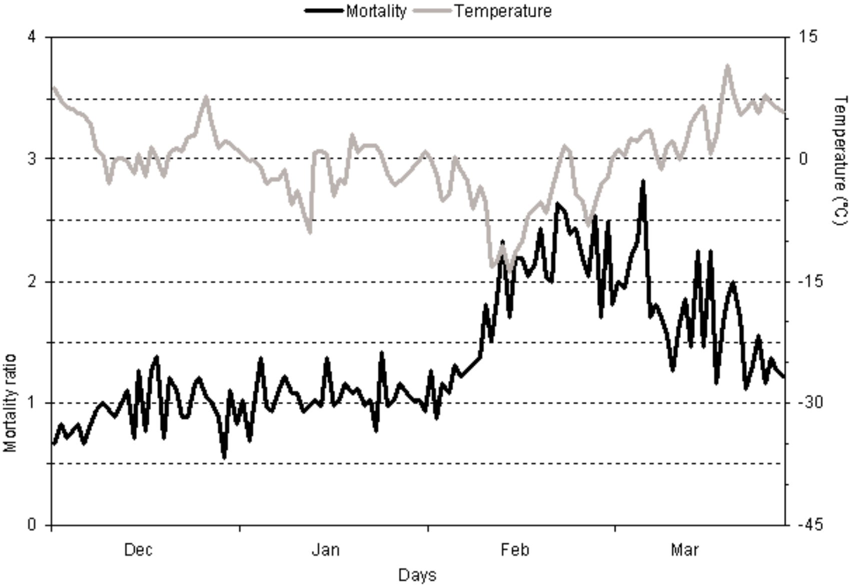


(b)Winter 1890-91

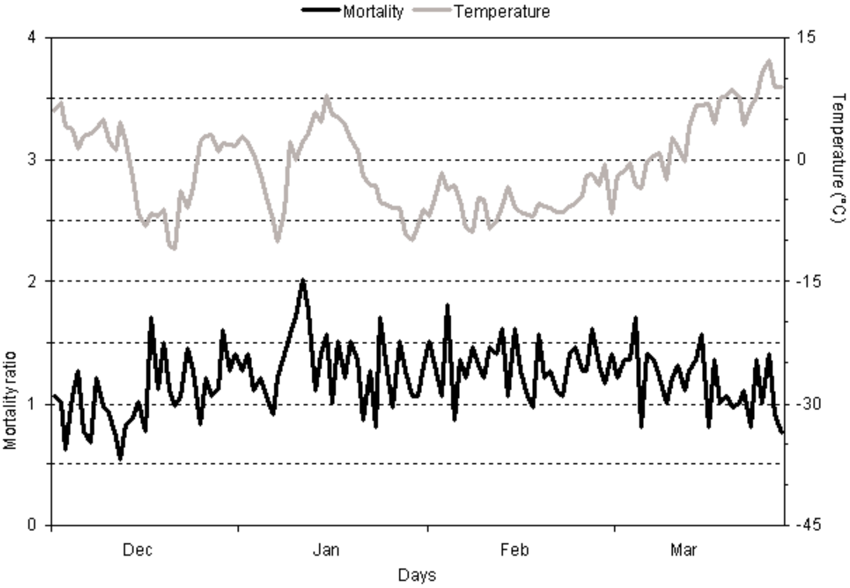


Mortality ratio = observed number of deaths per day divided by average number of deaths in the same year

(c)Winter 1928-29



(d)Winter 1946-47



Mortality ratio = observed number of deaths per day divided by average number of deaths in the same year

The regression coefficients for heat with respect to total mortality show a significant positive instantaneous effect of heat with a practically equal size in all four provinces. The 0.0372 effect of heat for day 0 in Drenthe means that a 1°C increase above the optimum temperature is associated with a 3.79 per cent increase in daily number of deaths[14]; for Gelderland, Groningen and Zeeland the increases were respectively 3.0, 3.6 and 4.1 per cent. A statistically significant delayed effect of heat was also observed in Drenthe, Gelderland and Zeeland for lag days 1-2; with respectively 1.8, 1.4 and 2.7 per cent increases in daily number of deaths for every 1°C increase above the optimum temperature, the size of that effect was lower than the immediate one. Delayed and significant effects were also observed in all four provinces for longer lags, except for the non-significant coefficient for lag days 3-6. The effect of heat for lag-days 7-14 and 15-30 varied from 1.4 and 2.3 per cent in Drenthe to 1.9 and 3.2 per cent in Gelderland, 1.6 to 2.9 per cent in Groningen and 3.1 and 8.5 per cent in Zeeland. During cold spells the regression models showed negative effects for the immediate temperature change, and these were significant in Drenthe, Groningen and Gelderland, where a 1°C decrease below the optimum temperature caused a less than 1 per cent decrease in daily mortality. In Drenthe and Gelderland there were significant delayed effects of temperature changes for lag-days 1-2 and 7-14, leading to respectively 1.3 and 0.8 per cent (Drenthe), 1.2 and 0.5 per cent (Groningen) and 1.1 and 1.0 percent (Groningen) increases in daily mortality. In general, the effects of heat were thus much stronger than those of cold. The pattern appeared to be similar for men and women in all provinces.

For most age groups the links between temperature and mortality were rather weak, with the exception of infant mortality (age <1 year). In all provinces immediate effects of heat were observed in all age groups, in most cases with stronger effects found for infants than for older age groups. Delayed effects (for days 7-14 and 15-30) were consistently found among the youngest age groups; for the elderly the situation varied by province. People aged 75 or older suffered from strongly increased effects as death ratios in Drenthe and Groningen show, in contrast to Gelderland and Zeeland. Remarkably enough, among infants the delayed consequences of heat (for lag days 7-14 and 15-30) were stronger than the immediate ones.

For cold, immediate effects were visible in Gelderland and Groningen among infants and children as well as among the elderly, but the effects were contrary to what could be expected, with lower-than-optimal temperatures leading to lower mortality. No immediate effects were observed in Drenthe and Zeeland. Delayed effects in the expected direction for lag days 1-2 were visible for infants and the elderly in Gelderland, Groningen and Drenthe, but not in Zeeland. For longer lags (7 days or more), the elderly in Drenthe, Groningen and Gelderland were undergoing mortality-increasing effects. However, the delayed effects for cold in lag days 15-30 had mortality-decreasing effects, particularly for infants. These compensatory effects suggest a harvesting effect.

Table A-2 also shows that the strength of the relationship between temperature and mortality varied by social class. In Zeeland, unskilled workers were the only group undergoing an immediate effect of heat, whereas in Gelderland, Groningen and Drenthe almost all social classes underwent a direct effect of exceptional heat. In these last three provinces the effects were felt strongest among workers, especially the unskilled. Delayed effects of heat were absent in Drenthe. In Gelderland, Groningen and Zeeland however delayed effects in lag days 7-14 and particularly lag-days 15-30 were present in almost all social classes and were extremely strong for the unskilled. For example, for unskilled workers in Gelderland the daily number of deaths rose by 6.2 per cent for every 1°C increase above the optimum temperature during the 15-30 days before the date of death; in Zeeland the comparable percentage for the unskilled was an even 15 per cent, but in other social classes increases of 10-12 per cent were observed.

Immediate mortality-increasing cold effects were absent in almost all social classes in Drenthe and Zeeland, but in Gelderland and Groningen small yet significant mortality-decreasing effects were observed among persons of almost all social classes. The delayed effects in lag days 15-30 had mortality-decreasing effects, particularly for unskilled workers. These compensatory effects again suggest a harvesting effect. There were however effects in the expected direction for lag-days 1-2 and 7-14 in Drenthe and Gelderland, and these were mainly present among unskilled workers.

All in all, the link between cold spells and mortality appeared to be much weaker than that between heat waves and mortality. Effects of heat waves were also much more delayed than those for cold spells.

Table A-3 presents the regression coefficients of the regression model applied to all summers and winters for 1855-1950. Models were estimated separately for four 25-year periods, to analyze changes in vulnerability to heat and cold over time. As in some of these time periods Zeeland in particular experienced no or very few heat waves or cold spells, we were only able to study the temperature-mortality connection by including all summers and winters in the model. The relationships between mortality and temperature, judged by the ordinary r^2, are more or less the same or even became stronger over time. The results indicate that the immediate effect of heat in all provinces is significant and rather strong over the entire period, yet the strength of the effect is not constant over time and a clear trend is not visible either. Whereas in Drenthe and Groningen the effect is clearly lower after 1930 than in any of the earlier periods for which data are available, in Zeeland and Gelderland the effects are as strong after 1930 as they were in 1855-1879.

Short-term delayed effects of heat (days 1-2) were absent in all periods in Zeeland, but in Gelderland, Groningen and Drenthe they appeared in most periods. Roughly speaking, one could say that in these three provinces in the most recent period these effects declined compared to earlier periods. Again, the longer-term delayed effects of heat (lag day 7 and beyond) are rather strong in all provinces. Although the exact time course differs slightly in the various provinces, it is absolutely clear that the delayed effect of heat has declined or even disappeared in the course of time, especially after 1930. This applies to all four provinces. To give an idea of the consequences, one can compare the regression coefficients between daily mortality and the optimum temperature minus the average temperatures on lag days 15-30 for the earliest and last periods: whereas in 1855-1879 a 1°C increase above the optimum temperature during lag days 15-30 implied a 5.5 per cent (Drenthe), 4.1 per cent (Gelderland), 5.8 per cent (Groningen) and 14 per cent (Zeeland) increase in number of deaths per day, the delayed effect of heat declined after 1930 to less than 1 per cent.

The direct effect of cold is negative in all provinces and periods, implying that temperatures below the optimal lead to a decline in daily mortality. That effect is significant across the periods and provinces and is only absent in the most recent period in Zeeland. Results more in line with expectations are observed for delayed effects. In all provinces significant mortality-increasing effects are found for below-optimal temperatures during lag days 1-2, disappearing after 1930. For lag days 3-6 and 7-14 mortality-increasing effects of colder-than-optimal temperatures are observed as well, but there is no question here of a decline of that effect over time. For lag days 15-30 the effect changed from mortality-decreasing to mortality-increasing.

Table A-3 also allows us to find out whether in the course of time there was a change in vulnerability to extreme temperatures by social class. To that end, we studied how the effects of temperature affected unskilled workers and farmers in each time period. For unskilled workers we observe significant and rather strong immediate effects of above-optimal temperatures on daily mortality in all provinces. In Drenthe, Groningen and Zeeland that effect disappears after 1930, whereas in Gelderland one finds an even stronger effect after 1930 than before. Strong, prolonged delayed effects (lag days 7-14 and 15-30) are present in all provinces until 1930 but disappear after 1930.

For farmers the situation is different. Only in Gelderland is a direct and almost unchanged effect of heat observable. Delayed effects for lag-days 7-14 and 15-30 are observed for Gelderland and Zeeland in almost all periods. Here too, delayed heat effects are no longer visible after 1930.

In all provinces there is a mortality-reducing immediate effect of cold below the optimal temperature for unskilled workers. Short-term (lag days 1-2) delayed effects of cold in the expected direction (mortality-increasing) are found among unskilled workers and disappear only after 1900 or even only after 1930. Among farmers, immediate or delayed effects of cold are absent.

Table A-4 presents the results of a regression model in which the changing relationship between temperature and infant and old-age mortality is studied for four 25-year periods. The mean number of deaths per day in the first age group declined from 13.7 to 3.4, whereas the number of deaths among people aged 75 and older increased from 4.5 to 12.8. Infant mortality underwent strong immediate effects of heat in every province and almost every period. It is clear that the immediate effect of heat on mortality in the youngest age group decreases almost continuously over time in all four provinces; after 1930 it is only seen in Gelderland. Similar tendencies are visible for delayed effects of heat. For lag days 7-14 as well as 15-30 the very strong delayed effects that were visible from the beginning of the period declined everywhere, although they remained present even after 1930 in Drenthe and Gelderland. Whereas in 1855-1879 a 1°C increase above the optimum temperature during lag days 15-30 implied a 14.6 per cent (Drenthe), 10.7 per cent (Gelderland), 7.3 per cent (Groningen) and 22.7 per cent (Zeeland) increase in number of deaths per day, after 1930 the delayed effect of heat declined to 10.4 per cent (Drenthe), 9.1 per cent (Gelderland) , 3.4 per cent (Groningen) and 5.2 per cent (Zeeland). For cold, the immediate effects again were in the unexpected direction and were present in all provinces and periods. Significant mortality-increasing delayed effects were visible for lag days 1-2 in all provinces but disappeared after 1930.

In the age group 75 years and older there was a clear immediate effect of heat in all provinces; over time, that effect strongly decreased in Drenthe but remained at more or less the same level in the other provinces. Strong delayed effects for lag days 7-14 and 15-30 were present in Drenthe but absent in other provinces. Remarkably enough, cold had direct mortality-decreasing effects for the elderly, which was visible in all provinces. Short-term delayed effects were observed until 1930, whereas in Zeeland, Groningen and Gelderland longer-term delayed effects (lag days 7-14 and 15-30) were also observed. A clear time trend was not visible though.

From several of the tables we observe a mortality-decreasing effect for lag days 15-30, suggesting a compensatory harvesting effect, particularly in the earlier periods. Although a thorough analysis of harvesting effects in the longer run falls beyond the scope of this study, exploratory analysis of mortality-decreasing effects in the longer run indeed suggests a harvesting effect after several months, particularly with respect to heat in the earlier periods. Comparing monthly mortality rates of the selected heat waves and cold spells (including an extended time interval after each) with the monthly mortality rates of preceding and subsequent years (not including heat waves and cold spells) indicates some harvesting effects for heat waves after 4 to 6 months and for cold after 6 to 8 months. From a health perspective heat waves and cold spells do affect life expectancy by reducing the number of years of life, but the higher the harvesting effect the lower the number of years of life lost.

CONCLUSION AND DISCUSSION

Our analysis is to our knowledge the first one in which the relationship between temperature and mortality was tested for a long historical period with rigorous statistical methods using rather refined temperature and mortality data. Our results might have been affected by the fact that our weather stations were at some distance from the area for which we had mortality data, but in general we think that that distance was not so far that it made our results untrustworthy. One might also question whether the choice of optimum temperature was the best possible; it might be the case that that optimum was different in the period that we studied or that it varied by region or age group. The range of optimal temperatures used so far in present-day studies is so small that we do not think this would lead to completely different results.

Our conclusions can be summarized as follows. Our study showed that between 1855 and 1950 total mortality underwent an immediate increase when temperature rose above the optimal value, the size of that effect being more or less the same in all four provinces. We also observed higher mortality related to increases in temperature 1-2 days before the day of death, and strong delayed effects for lag days 7-14 and 15-30. This pattern was observed for men and women. Effects of heat were strongest for infants (mortality below age 1) and delayed effects (for days 7-14 and 15-30) were consistently found among the youngest age groups too. Immediate effects of cold were contrary to what could be expected, with lower-than-optimal temperatures leading to lower mortality. In general one could say that the immediate effects of heat were felt more strongly among unskilled workers, whereas delayed effects in lag days 7-14 and 15-30 were extremely strong for unskilled workers too. All in all, the relationship between cold spells and mortality appeared to be much weaker than that between heat waves and mortality. Effects of heat waves were also much more delayed than those for cold spells.

The immediate effects of heat were not constant over time but no clear trend was visible. Short-term delayed effects of heat as well as longer-term delayed effects declined from 1900 or 1930 on. Temperatures below the optimum during lag days 1-2 increased mortality, but this effect disappeared after 1930 too. Vulnerability of unskilled workers to heat declined after 1930, for immediate as well as longer-time delayed effects. For the youngest age group a decline over time in the strength of the immediate effect of heat on mortality is visible, and similar tendencies were found for the longer-term delayed effects of heat.

The present study corroborates in a rigorous way many of the conclusions made by contemporaries based on much simpler methods about the relationship between temperature and mortality. For example, our study confirms the outcomes of studies of early-twentieth-century doctors such as Heynsius van den Berg, De Lange and others (De Lange, 1913; Gezondheidscommissie 's-Gravenhage, 1913; Heynsius van den Berg, 1912) that heat (and to a lesser degree cold) had 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 contrary to the situation nowadays, the effects of extreme heat were stronger for longer lag periods.

We also found that children were by far the most vulnerable group when temperature reached extremely high or low values. Whereas present-day studies always find a strong effect of extreme temperatures on the mortality levels of the elderly, this was hardly visible in our data set. Our study also confirmed that the lowest social class was the most vulnerable one during temperature fluctuations. The strongest direct and delayed effects of heat were found for unskilled workers. We also observed strong regional differences in the effect of heat on mortality—in particular, Zeeland endured strongly increased death rates during extreme weather conditions, a result that is in line with observations of contemporaries (Saltet & Falkenburg, 1907; Wybrands, 1914).

The few studies that describe long-term changes in the temperature-mortality link have focused on the reduced effects of cold and have described these changes as a consequence of diminished exposure thanks to improved housing and working conditions, clothing and footwear, and transportation. The elderly were more likely than other groups to live in homes with insufficient heating and may have been reluctant to turn on the heat because of the additional, perhaps unaffordable expense involved. Their economic and housing situation has improved considerably. Indoor cold exposure (a result of poor housing conditions, inadequate heating and large temperature differences between rooms) and exposure to cold during brief excursions outdoors have been especially reduced. Cold-related mortality was partly due to increased air pollution with SO_2 at a time when home heating was done mainly with coal. The transition to other heating methods has played a role in the decrease of excess winter mortality. Also, delayed effects of winter cold such as depleted fuel supplies and deterioration of the quality of food became less powerful (Kunst *et al.*, 1991).

Studies that observed decreases in the effect of heat on mortality are rather rare and do not specifically refer to infants, the age group that underwent the strongest change (Carson *et al.*, 2006; Hare, Moran, & Macfarlane, 1981). Given the prominent role that infant deaths played in the temperature-mortality relationship it is clear that the causes of changes over time in the effect of heat as well as the reasons behind the higher vulnerability of unskilled workers and the regional differences in vulnerability should be primarily sought in the series of factors affecting infant mortality.

The strong effects of heat that were observed among infants—effects that are no longer visible nowadays—were caused mainly by high rates of gastrointestinal diseases (Rombouts, 1902, 98, 102). In normal years, mortality due to "diarrhea and enteritis" and other acute gastrointestinal conditions was already characterized by a strong summer peak, even more so when temperatures were extremely high for a longer period[15]. High mortality due to gastrointestinal diseases was first of all a consequence of high proportions of artificially fed children. Huck (1997) even argued that decreased incidence and duration of breastfeeding and the supplementation of breast milk with cow's milk and other foods were the main reasons that the winter peak in infant mortality (January to March) in English towns changed into a summer peak in the nineteenth century (see also Wybrands, 1914, 91, for a comparable trend in Hamburg). The quality of foods such as milk and bread porridge deteriorated at high temperatures; the quality of water, used to dilute milk or prepare other foods, was extremely bad as well during periods of heat and drought; and purity of feeding bottles and teats could not be guaranteed. In poor homes there was no cool place to keep either condensed or fresh milk in the summer months (Fildes, 1998). Over time, however, infants became less and less sensitive to temperature fluctuations: increased frequency and duration of breast-feeding, increased use of proprietary artificial food, improvements in the quality of feeding bottles and of drinking water and milk, etc. have contributed to this change. Insects, responsible for the transmission of gastrointestinal diseases, have decreased in number with the advent of modern farming methods, changes in settlement and water management, the construction of sewers and improved public hygiene (McDowall, 1981).

Housing conditions also played a role. High housing density and sanitation problems facilitated the spread of disease during hot weather, but starting in the first decades of the twentieth century the crowding of people indoors (which increases temperatures and humidity) and cooking in living spaces (which has the same effect) decreased. More and better bedding and clothing for infants and decreased bed-sharing positively affected the capacity of infants to maintain a stable body temperature (Watson, Potter, Gallucci, & Lumley, 1998). Changes in food production, storage and distribution were another important factor. The growth of refrigerated food storage reduced mortality from many lethal infectious diseases during the summer months (Ellis, 1972). Food availability (fruits and vegetables) improved and could have a positive effect on weaned and breastfed children via their mothers.

Most of these factors also played a role in the excessive vulnerability of unskilled workers in the past, in the higher vulnerability of infants in Zeeland and in the improvement of the position of unskilled workers over time. Poor unskilled industrial and farm workers and their family members were tremendously vulnerable to extreme weather circumstances as a consequence of bad and crowded housing, insufficient clothing and footwear, harsh working conditions and infant malnutrition (due to low frequency of breastfeeding and inadequate artificial feeding). For a long time, infant mortality in Zeeland was by far the highest in the Netherlands, a combined effect of low incidence of breastfeeding and the atrocious condition of the drinking water and sanitation (Commissie belast met het onderzoek naar den toestand der kinderen in fabrieken arbeidende, 1869; Fokker, 1877). The gradual salinization of surface and ground water provided an ideal environment for the larvae of the malaria-carrying mosquito, thereby making malaria virtually endemic in this part of the Netherlands until about 1870, especially during summer periods. It was a mixture of factors which improved the situation of the lowest social class and that of the worst-faring province: increased frequency and duration of breastfeeding, increased use of proprietary artificial food for infants, better quality of drinking water and milk, improved housing conditions and sanitation, changes in food storage facilities, better clothing for infants, heating of homes, decreased dwelling density, changes in water management, etc. Cultural, technological and economic changes were the driving forces behind this decreased vulnerability to extreme weather conditions.

Unfortunately we were not able to study the specific effects of extreme heat in a real urban environment. Klinenberg (2002, 230-235) has convincingly shown how extreme weather conditions might lead to disastrous consequences for vulnerable residents in contemporary cities due to isolation, pointing to the rise of an aging population of urban residents living alone without sources of contact and social support, and extreme social and economic inequality manifest in spatial concentration and social separation of the affluent and the impoverished. In several aspects the nineteenth century city was different from present-day urban areas. It is argued that elites intermingled freely with lower strata members, especially servants, and could not remain isolated from them. Only starting in the late nineteenth century did more affluent groups distance themselves from higher mortality groups and areas, as the use of servants declined and residential segregation increased (Smith, 1991). Furthermore, there is no doubt that in the past families were major providers of health care for the weak and the elderly, and this might have led to a less isolated existence of the latter. In the near future, death certificates for the larger cities in the Netherlands will become available for the same period that is studied here. The "social autopsy" of temperature disasters that will then become possible will teach us a great deal about the living conditions of the urban population in the nineteenth and early twentieth centuries.

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NOTES

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2. High death rates due to winter cold remained a topic in temperate zones of Western Europe as thousands of extra persons died there in extremely cold winters (Analitis *et al.*, 2008; Baccini *et al.*, 2008; Healy, 2003; Keatinge *et al.*, 1997; McMichael *et al.*, 2008).

3. There is also some debate concerning the comparative impact of minimum, maximum and average temperatures on mortality (Kalkstein & Davis, 1989).

4. Data for Gelderland presently cover only municipalities alphabetically up to the letter V, and relate to 75 per cent of the total number of deaths in the province.

5. Times of observation were not standardized for pre-1880s observations. For the Vlissingen station, for example, temperature (in degrees Celsius) was measured starting December 1, 1854 at 9:00, 12:00, and 15:00 hours. Starting October 7, 1855, minimum and maximum temperatures were recorded. Starting December 1, 1857, temperature

measurements took place at 8:00, 12:00 and 15:00 hours, and starting April 1, 1859 at 8:00, 12:00 and 14:00 hours, but two years later, on April 1, 1861, recording took place at 8:00, 14:00 and 20:00 hours.

6. The measurements in all three stations were homogenized by taking into account the changing position and the changing times of the day. The method estimates a daily temperature (T) pattern modeled by a sine curve (for morning temperature rise and afternoon cooling) and a negative exponential curve (for evening and night cooling) with parameters estimated by Van Engelen and Geurts (1983) (for times of minimum and maximum temperature, sunrise and sunset times, and evening cooling-down tempo) using two or three readings (R).

7. The location of the weather stations for Gelderland and Drenthe/Groningen changed during the researched period. In the following we refer to weather stations as if they were located in the province for which we have mortality data.

8. The Hellmann or cold value is calculated by the summation of all 24-hour mean temperatures below 0°C over the period 1 November – 31 March without the minus sign.

9. The heat value is calculated by the summation of all 24-hour mean temperature number of degrees above 18 °C over the period 1 May – 31 October.

10. Level 5 includes executives, general policymakers, supra-local businessmen, non-manual super-skilled workers and members of the nobility. Level 4 includes supervisors of skilled workers, local businessmen, manual super-skilled workers and non-manual skilled persons. In level 3 we find supervisors of semi-skilled and unskilled workers, and manual skilled workers. Level 2 has the locally oriented self-employed with a minimal capital and semi-skilled workers. Level 1 comprises unskilled workers.

11. The time span covers some periods with exceptionally high mortality, e. g. the Spanish flu pandemic of 1918 and World War II (May 1940 to May 1945). However, no temperature measurements are available from the Eelde and Vlissingen stations for the period October 1944 to July 1945. Both these high-mortality periods and the period with missing temperature data were excluded from the regression analyses.

12. For instance, the summer of 1921 was the second hottest in Zeeland but ranked only average in the other provinces, therefore it was not selected. On the other hand, the summer of 1884 ranked relatively high only in Gelderland and Zeeland but still ranked fourth on average and was thus selected.

13. 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 for the observed dependent variable and estimated values. Cameron and Windmeijer (Cameron & 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". They do however conclude that "use of any of these measures […] is more informative than the current practice of not computing an R^2". As a measure of goodness of fit, additionally to the ordinary squared multiple correlation coefficient r^2 we also use an overdispersion-based r^2 developed for negative binomial models (Miaou, 1996; Miaou, Lu, & Lum, 1996). $r^2 = 1 - (\alpha / \alpha_{max})$, 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.

14. Calculated as transformation of the regression coefficient using the formula 100 x (e - 1).

15. In Zeeland, for example, these gastrointestinal conditions caused a doubling in total number of deaths in July and August; in the exceptionally hot summer of 1911 compared to 1910 and 1912 they doubled the total death toll in July and increased the number of deaths in August by a factor of 4 and in September by a factor of 2.5.

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SUMMARY

To gain insight into the changing impact of cold and heat on mortality, we analyzed Dutch individual death records in relation to daily temperatures for the 1855-1950 period for four of the eleven Dutch provinces. By making use of negative binomial regression models we studied whether the effect of extreme heat and cold varied by province, age, sex and social class, and analyzed the changes in vulnerability to temperature fluctuations. Our study showed that between 1855 and 1950 total mortality underwent an immediate increase when temperature rose above the optimal value, the size of that effect being more or less the same in all four provinces. We observed increases in mortality related to temperature increases 1-2 days before the day of death, and strong delayed effects for lag days 7-14 and 15-30. The immediate and delayed effects of heat were strongest for infants. Immediate effects of cold were contrary to what could be expected. The immediate and delayed effects of heat were felt the strongest among unskilled workers. Short-term delayed effects of heat as well as longer-term delayed effects declined from 1900 and 1930 on. The vulnerability of unskilled workers and infants to heat declined after 1930.

RÉSUMÉ

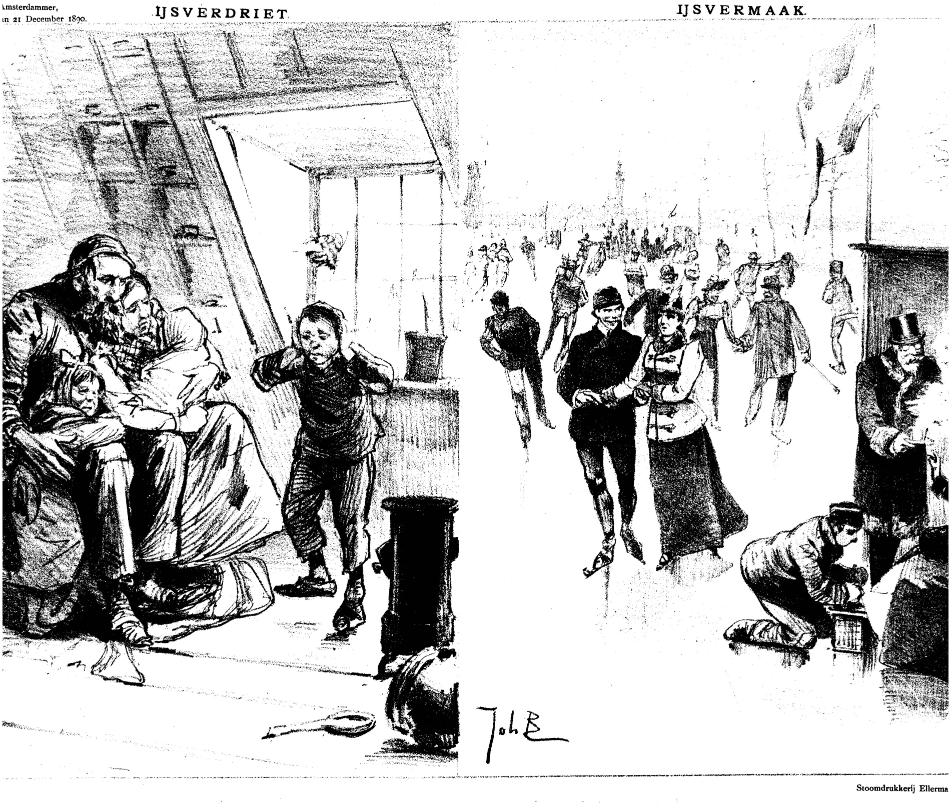
Le changement à long terme des relations entre les variations temporelles de la mortalité et celles des températures offre une excellente occasion d'approfondir notre connaissance des conséquences du changement climatique global pour la santé publique. La connaissance de ces changements a en même temps une très grande importance pour les historiens parce qu'elle fournit des informations pertinentes sur l'évolution du degré de vulnérabilité de la population face aux chocs externes tels que les vagues de chaleur ou de froid.

Pour analyser cette association, nous avons utilisé plus de 1,8 million de certificats de décès provenant de quatre des onze provinces néerlandaises et des données sur les températures moyennes quotidiennes de trois stations météorologiques pour la période 1855-1950. Le nombre quotidien des décès a été modélisé à l'aide d'un modèle de régression binomiale négative avec des décalages du jour 1 jusqu'au jour 30. Le modèle nous permet d'estimer simultanément les effets de périodes de froid et de chaleur, car les températures sont mesurées comme des déviations d'une température optimale pour laquelle la mortalité atteint son plus bas niveau. Nous avons adopté successivement deux approches pour analyser les relations entre la chaleur et le froid intenses et la mortalité : une première approche consiste à s'intéresser à des années caractérisées par des vagues de chaleur ou froid ; une seconde approche consiste à analyser l'association entre les températures et la mortalité pour tous les étés et hivers.

Notre premier objectif était de découvrir si les effets des fluctuations de température varient par province, âge, sexe et classe sociale, et de voir si, à long terme, les changements des conditions de vie (qu'il s'agisse du travail, du logement [densité, chauffage], de l'alimentation, des transport, des vêtements, etc.) ont diminué la vulnérabilité des divers groupes.

Notre analyse a démontré qu'entre 1855 et 1950 la mortalité totale a connu un accroissement immédiat lorsque la température grimpait au dessus de la température optimale. Cet effet était presque le même dans toutes les régions. On a observé en particulier des élévations de la mortalité 1-2 jours après le début de la hausse de la température et des effets très forts 7-14 et 15-30 jours après. Chez les enfants, autant les effets immédiats que les effets retardés étaient les plus forts. Les ouvriers non qualifiés ont subi plus que d'autres groupes les effets immédiats et retardés de la chaleur. Au cours de la période, on observe une diminution des effets immédiats et retardés de la chaleur, en particulier dès les années 1900 et 1930. C'est particulièrement la vulnérabilité des enfants et des ouvriers non qualifiés par rapport à la chaleur qui s'est affaiblie après 1930.

Political cartoon from Johan Braakensiek (1858-1940) in De Amsterdammer*, December 21, 1890*



Gedenkt „Liefdadigheid naar vermogen."

"Whereas the rich enjoyed themselves on ice-skating rinks, in the houses of the day laborers fuel was lacking and the streaming cold kept creeping through roofs, cracks, and slits, causing the death of infants".
Herman de Man (1898-1946), *De barre winter van negentig* (The barren winter of the nineties), Baarn: Bosch & Keunig,'1936.
Text below: Remember: "Charity according to one's means".
Text upper left: Ice sorrow
Text upper right: Ice enjoyment

Tab. A-1 *Characteristics of the Mortality and Temperature Data in the Dutch Provinces of Drenthe, Gelderland , Groningen and Zeeland by Period, 1855-1950*

	Drenthe[a]				Gelderland[b]				Groningen[a]				Zeeland[c]				Total
	1855-79	1880-04	1905-29	1930-50[d]	1855-79	1880-04	1905-29	1930-50[d]	1855-79	1880-04	1905-29	1930-50[d]	1855-79	1880-04	1905-29	1930-50[d]	
Number of observations (days)	9131	9131	9131	7670	9131	9131	9131	7670	9131	9131	9131	7670	9131	9131	9131	7670	140134
Number of deaths	62065	71599	71396	58431	191510	197915	185812	159424	138459	129060	119741	94469	129416	100259	78826	54919	1843301
Mean number of deaths per day	6.8	7.8	7.9	7.6	21.0	21.7	20.5	20.8	15.2	14.1	13.1	12.3	14.2	11.0	8.6	7.2	52.6
Percentage of deaths by sex																	
Females	48.1	46.1	44.9	42.9	48.0	46.9	46.4	44.6	47.6	47.5	47.7	46.3	48.5	48.0	48.0	47.1	46.9
Males	51.9	53.7	50.8	51.3	52.0	52.2	49.8	50.2	50.8	50.7	49.4	48.4	51.5	51.8	50.3	49.3	50.9
Percentage of deaths by age																	
Stillbirths	7.9	8.9	8.8	7.5	8.0	8.0	7.8	7.3	7.5	7.5	6.8	6.8	7.8	7.9	6.9	6.1	7.6
Age < 1 year	17.6	18.7	17.6	8.8	19.8	21.9	16.2	8.0	20.1	20.8	14.6	7.4	33.6	30.6	18.6	6.0	18.3
Age 1-4 years	14.9	12.9	9.4	4.1	13.2	10.8	7.5	3.2	13.1	11.2	7.4	3.3	12.3	9.1	5.6	2.1	9.1
Age 5-19 years	8.8	7.9	7.0	5.0	9.1	6.6	5.7	4.6	9.6	7.7	6.1	3.9	7.2	6.1	5.4	3.6	6.7
Age 20-49 years	20.4	17.3	16.0	15.9	17.3	14.5	14.6	14.5	20.3	16.0	15.7	12.6	15.2	12.1	13.3	12.5	15.5
Age 50-74 years	22.2	2.4	25.2	32.7	22.5	25.2	28.8	35.4	21.0	23.1	28.1	35.6	17.6	21.5	27.1	37.7	25.4
Age 75 years or older	8.0	10.2	15.9	25.8	9.9	12.7	19.2	26.9	8.2	13.5	21.3	30.3	6.1	12.6	22.9	31.9	16.3
Percentage of deaths by social class																	
Unskilled workers	29.5	34.2	32.1	17.1	30.9	28.8	20.5	11.0	34.4	32.9	25.5	14.8	47.1	37.3	25.4	12.6	27.5
Semi-skilled workers	3.9	3.4	3.1	3.5	6.6	6.8	5.6	4.9	7.7	6.1	5.3	4.4	8.0	7.2	6.1	4.7	5.8
Skilled workers	7.8	7.4	6.3	5.5	12.7	14.4	10.3	7.9	13.1	12.4	8.8	6.6	9.5	10.0	7.7	6.0	10.0
Farmers	18.1	17.8	16.8	13.5	14.1	15.5	15.8	11.7	10.7	8.2	6.4	5.3	8.6	7.9	7.6	6.4	11.7
Middle class (without farmers)	8.9	8.8	7.3	6.4	8.3	9.4	7.9	7.8	15.0	13.5	9.7	7.8	13.3	13.7	9.4	7.3	9.9
Elite	0.8	0.7	0.7	1.2	1.4	1.4	1.3	1.8	1.6	1.5	1.1	1.5	1.3	1.2	1.1	1.3	1.3
Unknown	30.9	27.6	33.7	52.8	26.0	23.6	38.6	54.9	17.6	25.5	43.1	59.6	12.2	22.7	42.7	61.7	33.7
Mean temperatures (° C)																	
Daily (24 hour) mean	8.7	8.5	8.7	9.1	9.6	9.3	9.1	9.4	8.7	8.5	8.7	9.1	9.9	10.0	10.1	10.1	9.4
Daily (24 hour) minimum	5.3	4.8	5.2	5.9	6.3	5.8	5.0	5.3	5.3	4.8	5.2	5.9	7.0	7.5	8.1	7.6	6.1
Daily (24 hour) maximum	11.3	11.8	12.3	12.5	13.0	12.8	13.4	13.7	11.3	11.8	12.3	12.5	12.3	12.4	12.1	12.7	12.5
Mean number of hot/cold days per year																	
Summer days (max >= 25 ° C)	8.6	14.2	14.0	17.9	19.4	17.0	18.7	26.0	8.6	14.2	14.0	17.9	9.0	7.6	7.2	10.1	14.0
Tropical days (max >= 30 ° C)	0.5	1.8	2.1	3.6	2.2	1.6	2.5	4.4	0.5	1.8	2.1	3.6	0.6	0.2	0.7	0.6	1.7
Ice days (max < 0 ° C)	20.1	18.6	13.7	17.0	14.7	13.1	8.8	13.4	20.1	18.6	13.7	17.0	10.0	8.6	8.0	10.0	13.0
Sharp frost days (max < 10 ° C)	2.8	3.1	2.9	4.1	3.2	2.5	3.6	5.0	2.8	3.1	2.9	4.1	0.7	0.6	0.7	0.8	2.5
Mean heat and cold values[e]																	
Heat value	32	42	39	60	74	64	44	71	32	42	39	60	46	59	59	55	53
Hellmann (or cold) value	88	104	82	104	82	88	71	97	88	104	82	104	36	47	36	50	73
Number of heat waves/cold spells[f]																	
Heat waves	1	4	7	6	3	3	8	13	1	4	7	6	1	0	1	2	31
Cold spells	6	9	6	10	10	9	4	10	6	9	6	10	2	2	2	2	42

a Temperature measurements from Groningen (1855-1905) and Eelde (1906-1950) stations

b Temperature measurements from Utrecht (1855-1896) and De Bilt (1897-1950) stations

c Temperature measurements from Vlissingen station

d No temperature measurements from October 1944 to July 1945

e The Hellmann (or cold) value is the summation of all 24 hour mean temperatures below 0°C over the period 1 November - 31 March without minus sign; the heat value is the summation of all 24 hour mean temperature number of degrees above 18 °C over the period 1 May - 31 October

f A heat wave is a consecutive series of at least 5 summer days (maximum temperature 25°C) including at least 3 tropical days (maximum temperature 30°C); a cold spell is a consecutive series of at least 5 ice days (maximum temperature < 0°C) including at least 3 days with severe frost (maximum temperature < -10°C).

Tab. A-2a *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 Drenthe during Heat Waves and Cold Spells in the Period 1855-1950*[a]

	Total[b]	Sex		Age groups						Social class[c]				
	mortality	females	males	< 1	1-4	5-19	20-49	50-74	75+	unskilled	semi sk.	skilled	farmers	mid/high
Number of Observations	6025	6025	6025	6025	6025	6025	6025	6025	6025	6025	6025	6025	6025	6025
Mean no. of deaths (± SD)	7.4(±3.4)	3.4(±2.1)	3.9(±2.2)	1.3(±1.3)	0.8(±1.0)	0.5(±0.7)	1.2(±1.2)	1.9(±1.5)	1.1(±1.2)	2.3(±1.7)	0.2(±0.5)	0.5(±0.7)	1.2(±1.2)	0.6(±0.8)
Heat														
day 0	0.0372**	0.0349**	0.0409**	0.0276*	0.0467**	0.0415*	0.0598**	0.0417**	0.0446**	0.0432**	0.0612*	0.0561**	0.0183	0.0498**
lag-days 1-2	0.0177**	0.0143	0.0188*	0.0297	-0.0098	0.0198	-0.0026	0.0157	0.0347	-0.0005	0.0499	0.0048	0.0239	-0.0040
lag days 3-6	0.0011	0.0048	-0.0031	0.0049	0.0275	-0.0030	-0.0282	-0.0002	0.0217	-0.0010	0.0156	-0.0026	0.0020	-0.0078
lag days 7-14	0.0142*	0.0128	0.0145	0.0534**	0.0040	-0.0372	-0.0145	0.0014	0.0479**	0.0219	-0.0423	0.0272	-0.0153	0.0490*
lag days 15-30	0.0227**	0.0189	0.0175	0.0746**	0.0115	-0.0646*	-0.0299	0.0190	0.0663**	0.0238	0.0411	0.0276	-0.0105	0.0209
Cold														
day 0	-0.0085**	-0.0085*	-0.0087*	-0.0122	-0.0107	0.0011	-0.0017	-0.0108*	-0.0105	-0.0059	-0.0143	-0.0055	-0.0064	-0.0108
lag-days 1-2	0.0131**	0.0148**	0.0117**	0.0220**	0.0142	-0.0008	0.0018	0.0156**	0.0165*	0.0130*	0.0250	0.0137	0.0042	0.0109
lag days 3-6	0.0002	-0.0007	0.0010	0.0011	-0.0103	-0.0032	-0.0041	0.0025	0.0138*	-0.0052	-0.0129	-0.0041	0.0050	-0.0056
lag days 7-14	0.0083**	0.0109**	0.0071*	-0.0036	0.0119	0.0076	0.0046	0.0137**	0.0110	0.0089*	0.0103	-0.0077	0.0018	0.0054
lag days 15-30	-0.0028	-0.0029	-0.0024	-0.0168**	0.0056	0.0050	0.0097	-0.0027	-0.0056	-0.0141**	0.0088	0.0006	-0.0031	0.0051
Seasonal trend	0.1061**	0.0886**	0.1142**	0.1534**	0.0135	0.0453	0.0450*	0.1023**	0.2034**	0.1619**	0.0589	0.1378**	0.1108**	0.0807**
α	0.0341**	0.0570**	0.0372**	0.1987**	0.2928**	0.2668**	0.0741**	0.0502**	0.1867**	0.1202**	0.1678**	0.1678**	0.0959**	0.0982**
r^2	0.4075	0.2978	0.3190	0.1683	0.0817	0.0962	0.1441	0.3019	0.3345	0.2279	0.0974	0.1015	0.1521	0.1004
r^2_α	0.4894	0.3668	0.4842	0.1136	0.0526	0.0900	0.1978	0.5319	0.4584	0.2235	0.1523	0.1248	0.1809	0.1388

a Except October-November 1918, May 1940-July 1945

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 = overdispersion parameter, r^2 = ordinary correlation coefficient between observed and estimated dependent variable, overdispersion based $r^2_\alpha = 1 - (\alpha / \alpha_{max})$, with α_{max} estimated from model with a constant term and overdispersion parameter only (see Miaou, 1996).

Tab. A-2b *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 Gelderland during Heat Waves and Cold Spells in the Period 1855-1950*[a]

	Total[b]	Sex		Age groups						Social class[c]				
	mortality	females	males	< 1	1-4	5-19	20-49	50-74	75+	unskilled	semi sk.	skilled	farmers	mid/high
Number of Observations	2210	2210	2210	2210	2210	2210	2210	2210	2210	2210	2210	2210	2210	2210
Mean no. of deaths (± SD)	10.2(±5.5)	4.9(±3.2)	5.2(±3.2)	2.4(±2.7)	0.8(±1.1)	0.6(±0.9)	1.3(±1.5)	2.6(±2.0)	1.7(±1.7)	3.3(±3.4)	0.7(±0.9)	0.9(±1.1)	0.7(±0.9)	1.2(±1.3)
Heat														
day 0	0.0399**	0.0515**	0.0327**	0.0508*	0.0885**	0.0193	0.0584**	0.0372*	0.0185	0.0562**	-0.0217	-0.0068	0.0529	0.0378
lag-days 1-2	0.0268*	0.0209	0.0323*	0.0336	0.0642	0.0258	0.0288	0.0282	0.0401	0.0091	0.0210	0.0779**	0.0223	0.0414
lag days 3-6	-0.0033	-0.0217	0.0102	0.0102	-0.0303	0.0795*	-0.0438	-0.0129	-0.0231	0.0301	-0.0019	0.0224	-0.0167	-0.0214
lag days 7-14	0.0307**	0.0335*	0.0318*	0.1013**	-0.0063	-0.0095	0.0224	0.0101	0.0027	0.0626**	0.0507**	0.0601*	0.0373	0.0194
lag days 15-30	0.0812**	0.0889**	0.0794**	0.2377**	0.0758*	0.0404	-0.0148	0.0337	-0.0037	0.1401**	0.1284**	0.1142	0.0951**	0.1205**
Cold														
day 0	-0.0019	-0.0063	0.0029	-0.0106	-0.0158	-0.0052	-0.0246*	0.0142	0.0091	-0.0029	-0.0278**	-0.0196	0.0104	-0.0158
lag-days 1-2	0.0093	0.0136	0.0055	0.0100	0.0165	-0.0351	0.0271*	0.0055	0.0043	0.0028	0.0242*	0.0368*	-0.0199	0.0042
lag days 3-6	0.0049	0.0031	0.0055	0.0144	-0.0176	0.0181	-0.0093	-0.0003	0.0212*	0.0071	0.0015	0.0001	0.0066	0.0231
lag days 7-14	0.0107*	0.0127*	0.0092	0.0056	0.0292*	0.0048	0.0176	0.0176*	0.0162*	0.0080	0.0028	0.0147	0.0289*	0.0010
lag days 15-30	-0.0016	0.0009	-0.0042	-0.0267**	-0.0021	0.0044	-0.0048	0.0030	0.0253**	-0.0123	-0.0027	-0.0214*	-0.0134	-0.0010
Seasonal trend	0.0938**	0.0981**	0.0976**	0.2329**	0.2280**	0.2016**	0.1514**	0.0139**	-0.1450**	0.2307**	0.1636**	0.1431**	0.1212**	0.1373**
α	0.0445**	0.0519**	0.0459**	0.3299**	0.1525**	0.2042**	0.0864**	0.0668**	0.0508**	0.1537**	0.0871**	0.0476	0.0000	0.1452**
r^2	0.6889	0.6077	0.5976	0.5998	0.5237	0.4259	0.5233	0.4027	0.5385	0.7203	0.3311	0.4108	0.3478	0.4262
r^2_α	0.7433	0.7449	0.7464	0.6601	0.8174	0.7172	0.7943	0.5392	0.8446	0.8098	0.6948	0.8509	1.0000	0.6264

a Except October-November 1918, May 1940-July 1945

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 = overdispersion parameter, r^2 = ordinary correlation coefficient between observed and estimated dependent variable, overdispersion based $r^2_\alpha = 1 - (\alpha / \alpha_{max})$, with α_{max} estimated from model with a constant term and overdispersion parameter only (see Miaou, 1996).

Tab. A-2c *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 Groningen during Heat Waves and cold Spells in the Period 1855-1950*[a]

	Total[b]	Sex		Age groups						Social class[c]				
	mortality	females	males	< 1	1-4	5-19	20-49	50-74	75+	unskilled	semi sk.	skilled	farmers	mid/high
Number of Observations	6025	6025	6025	6025	6025	6025	6025	6025	6025	6025	6025	6025	6025	6025
Mean no. of deaths (± SD)	13.6(±5.0)	6.4(±3.1)	6.8(±3.1)	2.4(±2.0)	1.3(±1.4)	1.0(±1.1)	2.0(±1.8)	3.5(±2.2)	2.2(±2.0)	3.9(±2.5)	0.8(±1.0)	1.5(±1.4)	1.1(±1.1)	1.8(±1.6)
Heat														
day 0	0.0350**	0.0352**	0.0356**	-0.0610**	0.0197	0.0157	0.0317**	0.0329**	0.0286**	0.0413**	0.0337*	0.0421**	0.0006	0.0425**
lag-days 1-2	0.0058	0.0034	0.0080	0.0021	0.0049	-0.0078	-0.0032	0.0039	0.0262*	0.0030	0.0074	-0.0220	0.0469	0.0131
lag days 3-6	0.0174**	0.0183**	0.0184**	0.0189	0.0216	0.0048	0.0062	0.0236**	0.0308**	-0.0083	0.0275	0.0258	0.0183	0.0087
lag days 7-14	0.0154**	0.0157*	0.0147*	0.0689**	0.0218	-0.0042	-0.0132	-0.0071	0.0065	0.0211*	0.0004	0.0308*	0.0006	0.0342*
lag days 15-30	0.0288**	0.0302**	0.0274**	0.0914**	0.0155	0.0056	0.0058	0.0059	0.0323*	0.0411**	0.0599**	0.0309	0.0371	0.0386*
Cold														
day 0	-0.0089**	-0.0112**	-0.0077**	-0.0135**	-0.0096	-0.0149*	-0.0091	-0.0078*	-0.0066	-0.0117**	-0.0026	-0.0115*	-0.0141*	-0.0068
lag-days 1-2	0.0107**	0.0106**	0.0112**	0.0157*	0.0046	0.0141	0.0066	0.0150**	0.0115*	0.0111*	0.0077	0.0110	0.0165*	0.0076
lag days 3-6	0.0057**	0.0084**	0.0039	0.0063	-0.0007	-0.0054	-0.0016	0.0073*	0.0226**	0.0001	0.0093	0.0010	0.0002	-0.0020
lag days 7-14	0.0097**	0.0094**	0.0098**	-0.0007	0.0004	-0.0072	0.0050	0.0164**	0.0277**	0.0075*	-0.0140*	0.0008	0.0030	0.0060
lag days 15-30	-0.0082**	-0.0071**	-0.0121**	-0.0547**	-0.0391**	-0.0187**	-0.0181**	0.0136**	0.0372**	-0.0337**	-0.0234*	-0.0247*	-0.0279*	-0.0245*
Seasonal trend	0.0820**	0.0888**	0.0918**	0.2559**	0.3046**	0.2268**	0.1681**	-0.0480**	-0.1843**	0.2108**	0.1976**	0.1947**	0.2157**	0.2085**
α	0.0209**	0.0286**	0.0225**	0.1446**	0.2067**	0.1724**	0.0639**	0.0322**	0.1168**	0.0860**	0.0762**	0.0822**	0.0985**	0.0902**
r^2	0.5375	0.4483	0.4252	0.4244	0.3463	0.2556	0.3177	0.3990	0.4877	0.4217	0.2266	0.2829	0.2831	0.3430
r^2_α	0.6412	0.6160	0.6219	0.4849	0.4589	0.3804	0.5068	0.6325	0.6003	0.4978	0.4896	0.4737	0.5155	0.5119

a Except October-November 1918, May 1940-July 1945

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 ($p<0.01$)

= overdispersion parameter, r^2 = ordinary correlation coefficient between observed and estimated dependent variable, overdispersion based $r^2_\alpha = 1 - (\alpha / \alpha_{max})$, with α_{max} estimated from model with a constant term and overdispersion parameter only (see Miaou, 1996).

Tab. A-2d *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 1855-1950*[a]

	Total[b]	Sex		Age groups						Social class[c]				
	mortality	females	males	< 1	1-4	5-19	20-49	50-74	75+	unskilled	semi sk.	skilled	farmers	mid/high
Number of Observations	2210	2210	2210	2210	2210	2210	2210	2210	2210	2210	2210	2210	2210	2210
Mean no. of deaths (± SD)	10.2(±5.5)	4.9(±3.2)	5.2(±3.2)	2.4(±2.7)	0.8(±1.1)	0.6(±0.9)	1.3(±1.5)	2.6(±2.0)	1.7(±1.7)	3.3(±3.4)	0.7(±0.9)	0.9(±1.1)	0.7(±0.9)	1.2(±1.3)
Heat														
day 0	0.0399**	0.0515**	0.0327**	0.0508*	0.0885**	0.0193	0.0584**	0.0372*	0.0185	0.0562**	-0.0217	-0.0068	0.0529	0.0378
lag-days 1-2	0.0268*	0.0209	0.0323*	0.0336	0.0642	0.0258	0.0288	0.0282	0.0401	0.0091	0.0210	0.0779**	0.0223	0.0414
lag days 3-6	-0.0033	-0.0217	0.0102	0.0102	-0.0303	0.0795*	-0.0438	-0.0129	-0.0231	0.0301	-0.0019	0.0224	-0.0167	-0.0214
lag days 7-14	0.0307**	0.0335*	0.0318*	0.1013**	-0.0063	-0.0095	0.0224	0.0101	0.0027	0.0626**	0.0507**	0.0601*	0.0373	0.0194
lag days 15-30	0.0812**	0.0889**	0.0794**	0.2377**	0.0758*	0.0404	-0.0148	0.0337	-0.0037	0.1401**	0.1284**	0.1142	0.0951**	0.1205**
Cold														
day 0	-0.0019	-0.0063	0.0029	-0.0106	-0.0158	-0.0052	-0.0246*	0.0142	0.0091	-0.0029	-0.0278**	-0.0196	0.0104	-0.0158
lag-days 1-2	0.0093	0.0136	0.0055	0.0100	0.0165	-0.0351	0.0271*	0.0055	0.0043	0.0028	0.0242*	0.0368*	-0.0199	0.0042
lag days 3-6	0.0049	0.0031	0.0055	0.0144	-0.0176	0.0181	-0.0093	-0.0003	0.0212*	0.0071	0.0015	0.0001	0.0066	0.0231
lag days 7-14	0.0107*	0.0127*	0.0092	0.0056	0.0292*	0.0048	0.0176	0.0176*	0.0162*	0.0080	0.0028	0.0147	0.0289*	0.0010
lag days 15-30	-0.0016	0.0009	-0.0042	-0.0267**	-0.0021	0.0044	-0.0048	0.0030	0.0253**	-0.0123	-0.0027	-0.0214*	-0.0134	-0.0010
Seasonal trend	0.0938**	0.0981**	0.0976**	0.2329**	0.2280**	0.2016**	0.1514**	0.0139**	-0.1450**	0.2307**	0.1636**	0.1431**	0.1212**	0.1373**
α	0.0445**	0.0519**	0.0459**	0.3299**	0.1525**	0.2042**	0.0864**	0.0668**	0.0508**	0.1537**	0.0871**	0.0476	0.0000	0.1452**
r^2	0.6889	0.6077	0.5976	0.5998	0.5237	0.4259	0.5233	0.4027	0.5385	0.7203	0.3311	0.4108	0.3478	0.4262
r^2_α	0.7433	0.7449	0.7464	0.6601	0.8174	0.7172	0.7943	0.5392	0.8446	0.8098	0.6948	0.8509	1.0000	0.6264

a Except October-November 1918, May 1940-July 1945

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 = overdispersion parameter, r^2 = ordinary correlation coefficient between observed and estimated dependent variable, overdispersion based $r^2_\alpha = 1 - (\alpha / \alpha_{max})$, with α_{max} estimated from model with a constant term and overdispersion parameter only (see Miaou, 1996).

Tab. A-3a *Regression coefficients of Negative Binomial Regression between Daily total Mortality, Mortality of Unskilled Workers, Mortality of Farmers and Temperature with Different Time lags Controlled for Long-Term Mortality Trend and Season in the Dutch Province of Drenthe during all Summers and Winters per Period*[a]

	Total mortality[b]				Unskilled workers[b]				Farmers[b]			
	1855-79	1880-04	1905-29[a]	1930-50[a]	1855-79	1880-04	1905-29[a]	1930-50[a]	1855-79	1880-04	1905-29[a]	1930-50[a]
Number of observations	5306	5306	5232	3335	5306	5306	5232	3335	5306	5306	5232	3335
Mean no. of deaths (± SD)	6.7(±3.0)	7.8(±3.2)	7.5(±3.3)	6.8(±3.2)	2.0(±1.5)	2.7(±1.7)	2.4(±1.7)	1.2(±1.2)	1.2(±1.2)	1.4(±1.2)	1.3(±1.2)	1.0(±1.1)
Heat												
day 0	0.0379**	0.0307**	0.0345**	0.0266**	0.0430**	0.0326**	0.0321**	0.0208	0.0166	0.0473**	0.0216	0.0226
lag-days 1-2	0.0228*	-0.0084	0.0218**	0.0122	0.0211	-0.0071	0.0064	0.0188	0.0086	-0.0213	0.0357	-0.0117
lag days 3-6	0.0166	0.0201**	0.0037	-0.0016	0.0118	0.0224	0.0143	-0.0133	0.0510*	0.0300	0.0116	0.0069
lag days 7-14	0.0541**	0.0170*	0.0201*	-0.0144	0.0609**	0.0353**	0.0326*	-0.0290	0.0446	-0.0153	0.0115	-0.0104
lag days 15-30	0.0535**	0.0267*	0.0496**	0.0100	0.0298	0.0439*	0.0802**	-0.0138	0.0845**	-0.0230	0.0288	0.0334
Cold												
day 0	-0.0074*	-0.0054*	-0.0120**	-0.0116**	0.0025	-0.0013	-0.0125*	-0.0183*	-0.0218**	0.0012	-0.0072	-0.0080
lag-days 1-2	0.0206**	0.0138**	0.0103**	0.0070	0.0155*	0.0152**	0.0108	0.0047	0.0202*	0.0006	0.0060	0.0005
lag days 3-6	0.0049	0.0010	0.0045	0.0060	0.0050	-0.0026	0.0006	0.0083	0.0201**	0.0054	0.0005	0.0082
lag days 7-14	0.0007	0.0060*	0.0082**	0.0065	-0.0011	0.0011	-0.0001	0.0140	-0.0037	0.0124*	0.0002	0.0064
lag days 15-30	-0.0142**	-0.0127**	-0.0062*	0.0089*	-0.0278**	-0.0187**	-0.0198**	0.0383**	-0.0271**	-0.0142*	-0.0163*	0.0143
Seasonal trend	0.1434**	0.1177**	0.1201**	0.0717**	0.2337**	0.1451**	0.2185**	-0.1702**	0.2992**	0.0866**	0.2110**	-0.0025
α	0.0303**	0.0215**	0.0296**	0.0410**	0.0638**	0.0302**	0.0585**	0.1865**	0.0919**	0.0389**	0.0732**	0.2733**
R^2	0.3176	0.3623	0.3976	0.3918	0.2253	0.2036	0.2316	0.1790	0.2130	0.1672	0.1793	0.1200
R^2_α	0.3945	0.5108	0.5035	0.4518	0.3385	0.3716	0.3179	0.1708	0.3362	0.3578	0.2851	0.0785

a Except October-November 1918, May 1940-July 1945

b All models calculated with full model including seasonal time trend and temperature during different time lags

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

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

Tab. A-3b *Regression Coefficients of Negative Binomial Regression between Daily Total Mortality, Mortality of Unskilled Workers, Mortality of Farmers and Temperature with Different Time lags Controlled for Long-Term Mortality Trend and Season in the Dutch Province of Gelderland during all Summers and Winters per Period*[a]

	Total mortality[b]				Unskilled workers[b]				Farmers[b]			
	1855-79	1880-04	1905-29[a]	1930-50[a]	1855-79	1880-04	1905-29[a]	1930-50[a]	1855-79	1880-04	1905-29[a]	1930-50[a]
Number of observations	5306	5306	5291	3335	5306	5306	5291	3335	5306	5306	5291	3335
Mean no. of deaths (± SD)	20.7(±6.2)	21.7(±6.7)	19.8(±7.0)	18.6(±6.1)	6.4(±2.9)	6.3(±2.9)	4.1(±2.4)	2.1(±1.6)	2.9(±1.8)	3.3(±2.0)	3.1(±2.0)	2.3(±1.6)
Heat												
day 0	0.0282**	0.0251**	0.0347**	0.0307**	0.0292**	0.0271**	0.0342**	0.0517**	0.0396**	0.0219**	0.0321**	0.0310**
lag-days 1-2	-0.0002	0.0102*	0.0212**	0.0124*	0.0061	0.0119	0.0191	-0.0002	-0.0094	0.0010	0.0300*	0.0139
lag days 3-6	-0.0093*	0.0068	0.0056	-0.0016	-0.0121	0.0005	0.0200*	0.0095	-0.0112	0.0045	-0.0305**	-0.0140
lag days 7-14	0.0240**	0.0311**	0.0196**	-0.0088	0.0249**	0.0388**	0.0034	-0.0239	0.0134	0.0158	0.0370**	-0.0124
lag days 15-30	0.0398**	0.0417**	0.0546**	-0.0023	0.0466**	0.0567**	0.0973**	0.0055	0.0386**	0.0275*	0.0505**	-0.0308
Cold												
day 0	-0.0096**	-0.0095**	-0.0118**	-0.0081**	-0.0105**	-0.0130**	-0.0201**	-0.0160**	-0.0167**	-0.0094*	-0.0102**	-0.0106
lag-days 1-2	0.0179**	0.0146**	0.0104**	0.0032	0.0228**	0.0197**	0.0142**	0.0136	0.0226**	0.0078	0.0068	0.0094
lag days 3-6	0.0061**	0.0074**	0.0133**	0.0138**	0.0021	0.0070*	0.0039	0.0174**	0.0123**	0.0077	0.0106**	0.0140*
lag days 7-14	0.0048**	0.0052**	0.0072**	0.0042*	0.0019	0.0051	0.0010	0.0008	-0.0025	0.0035	0.0055	0.0066
lag days 15-30	-0.0097**	-0.0004	-0.0059**	0.0070**	-0.0036	-0.0050	-0.0346**	0.0230**	-0.0045	0.0028	-0.0129**	0.0122*
Seasonal trend	0.0388**	0.0241**	0.0423**	0.0233**	0.0263**	0.0304**	0.1271**	-0.0281**	0.0312**	0.0408**	0.0683**	-0.0140**
α	0.0172**	0.0181**	0.0224**	0.0130**	0.0270**	0.0211**	0.0543**	0.0435**	0.0199**	0.0280**	0.0319**	0.0247
R^2	0.5072	0.5394	0.6096	0.6036	0.3068	0.3571	0.3901	0.2616	0.2436	0.3147	0.3463	0.2713
R^2_α	0.5680	0.5877	0.6534	0.7416	0.4181	0.5560	0.5128	0.4757	0.5443	0.5651	0.6028	0.6043

a Except October-November 1918, May 1940-July 1945

b All models calculated with full model including seasonal time trend and temperature during different time lags

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

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

Tab. A-3c *Regression Coefficients of Negative Binomial Regression between Daily Total Mortality, mortality of Unskilled workers, Mortality of Farmers and Temperature with Different Time Lags Controlled for Long-Term Mortality Trend and Season in the Dutch Province of Groningen during all Summers and Winters per Period*[a]

	Total mortality[b]				Unskilled workers[b]				Farmers[b]			
	1855-79	1880-04	1905-29[a]	1930-50[a]	1855-79	1880-04	1905-29[a]	1930-50[a]	1855-79	1880-04	1905-29[a]	1930-50[a]
Number of observations	5306	5306	5232	3335	5306	5306	5232	3335	5306	5306	5232	3335
Mean no. of deaths (± SD)	15.1(±5.6)	14.1(±4.7)	12.5(±4.8)	11.8(±4.4)	5.2(±2.7)	4.7(±2.3)	3.2(±2.0)	1.7(±1.5)	1.6(±1.3)	1.1(±1.1)	0.8(±0.9)	0.6(±0.9)
Heat												
day 0	0.0421**	0.0236**	0.0381**	0.0178**	0.0537**	0.0326**	0.0418**	0.0073	0.0248	0.0111	-0.0018	0.0486*
lag-days 1-2	0.0144	0.0035	0.0169**	0.0172*	-0.0018	0.0027	0.0194	0.0242	0.0452*	0.0061	0.0641**	-0.0003
lag days 3-6	0.0273**	0.0174**	0.0156*	-0.0012	0.0211*	0.0052	0.0098	-0.0587**	-0.0000	0.0077	-0.0284	-0.0085
lag days 7-14	0.0441**	0.0186**	0.0176**	-0.0067	0.0487**	0.0381**	0.0231	0.0041	0.0239	-0.0085	0.0137	0.0385
lag days 15-30	0.0568**	-0.0259**	0.0453**	-0.0061	0.0537**	0.0323*	0.0627**	-0.0170	0.1053**	-0.0077	0.0358	-0.0156
Cold												
day 0	-0.0082**	-0.0105**	-0.0071**	-0.0122**	-0.0042	-0.0088*	-0.0104*	-0.0071	-0.0150**	-0.0121	-0.0043	-0.0200
lag-days 1-2	0.0145**	0.0101**	0.0088**	0.0065	0.0123**	0.0119**	0.0085	0.0003	0.0143*	0.0112	0.0086	0.0074
lag days 3-6	0.0077**	0.0069**	0.0085**	0.0120**	0.0093*	0.0001	0.0047	0.0124	0.0101	0.0056	-0.0132	0.0170
lag days 7-14	0.0047*	0.0057**	0.0137**	0.0049	-0.0041	0.0052	0.0075	0.0067	0.0058	0.0055	0.0124	0.0135
lag days 15-30	-0.0143**	-0.0025**	-0.0087**	0.0099**	-0.0194**	-0.0058	-0.0302**	-0.0017	-0.0065	-0.0154*	-0.0081	0.0197
Seasonal trend	0.0922**	0.0504**	0.0531**	0.0244**	0.0904**	0.0492**	0.1401**	0.0171	0.0712**	0.0981**	0.0890**	-0.0628
α	0.0443**	0.0171**	0.0220**	0.0189**	0.0510**	0.0118**	0.0446**	0.1558**	0.0250*	0.0363*	0.1329**	0.2789
R^2	0.3188	0.4275	0.5225	0.4923	0.2249	0.2029	0.2854	0.1505	0.1542	0.1587	0.1296	0.1270
R^2_α	0.2251	0.5301	0.6241	0.6332	0.2005	0.4505	0.4211	0.1088	0.3883	0.4024	0.1713	0.1219

a Except October-November 1918, May 1940-July 1945

b All models calculated with full model including seasonal time trend and temperature during different time lags

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

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

Tab. A-3d *Regression Coefficients of Negative Binomial Regression between Daily Total Mortality, Mortality of Unskilled Workers, mortality of Farmers 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}

	Total mortality^{b}				Unskilled workers^{b}				Farmers^{b}			
	1855-79	1880-04	1905-29^{a}	1930-50^{a}	1855-79	1880-04	1905-29^{a}	1930-50^{a}	1855-79	1880-04	1905-29^{a}	1930-50^{a}
Number of observations	5306	5306	5291	3305	5306	5306	5291	3305	5306	5306	5291	3305
Mean no. of deaths (± SD)	14.2(±5.1)	11.2(±4.2)	8.3(±3.8)	6.8(±3.2)	6.7(±3.2)	4.2(±2.3)	2.1(±1.7)	0.8(±0.9)	1.2(±1.1)	0.9(±0.9)	0.6(±0.8)	0.4(±0.6)
Heat												
day 0	0.0272**	0.0310**	0.0336**	0.0272**	0.0237**	0.0296**	0.0400**	-0.0081	0.0220	0.0261	0.0325	0.0169
lag-days 1-2	-0.0044	-0.0063	0.0033	0.0115	-0.0074	-0.0065	-0.0120	0.0478	0.0122	-0.0025	-0.0026	-0.0049
lag days 3-6	-0.0015	0.0081	0.0094	-0.0159	0.0049	0.0181*	0.0258*	-0.0379	-0.0351	-0.0099	-0.0045	0.0289
lag days 7-14	0.0467**	0.0598**	0.0299**	-0.0102	0.0501**	0.0661**	0.0443**	-0.0558	0.0722**	0.0248	0.0529*	-0.0317
lag days 15-30	0.1307**	0.0946**	0.0594**	0.0014	0.1425**	0.1143**	0.0934**	-0.0041	0.1359**	0.0960**	0.0588*	0.0529
Cold												
day 0	-0.0055*	-0.0072*	-0.0104**	-0.0069	-0.0051	-0.0139**	-0.0238**	0.0128	-0.0012	-0.0121	-0.0041	0.0070
lag-days 1-2	0.0168**	0.0143**	0.0113**	0.0077	0.0176**	0.0243**	0.0140	-0.0197	0.0030	0.0146	-0.0025	-0.0080
lag days 3-6	0.0080**	0.0079**	0.0116**	0.0096	0.0029	0.0042	0.0101	0.0264*	0.0107	-0.0091	0.0143	0.0299
lag days 7-14	0.0060*	0.0033	0.0095**	0.0079*	0.0047	0.0013	-0.0208**	0.0035	0.0056	0.0100	0.0118	0.0080
lag days 15-30	-0.0161**	0.0001	-0.0166**	0.0117**	-0.0183**	-0.0123**	-0.0390**	0.0129	-0.0058	0.0086	-0.0270	-0.0112
Seasonal trend	0.0653**	0.0436**	0.1259**	0.0239	0.1043**	0.1042**	0.3467**	-0.1186*	0.0296*	0.0813**	0.1534**	0.0298
α	0.0275**	0.0268**	0.0302**	0.0212**	0.0381**	0.0374**	0.0505**	0.0936**	0.0278*	0.0505*	0.0208	0.0273
R^2	0.4633	0.3893	0.4945	0.4566	0.4155	0.3328	0.4438	0.1190	0.1680	0.1206	0.1706	0.1282
R^2_α	0.4872	0.4317	0.6137	0.6668	0.5022	0.4716	0.7211	0.2112	0.4721	0.2741	0.6942	0.5811

a Except October-November 1918, May 1940-July 1945

b All models calculated with full model including seasonal time trend and temperature during different time lags

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

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

Tab. A-4a *Regression Coefficients of Negative Binomial Regression between Daily infant Mortality and Temperature with Different Time Lags Controlled for Long-Term Mortality Trend and Season during all Summers and Winters per Province and Period*[a]

	Drenthe[b]				Groningen[b]			
	1855-79	1880-04	1905-29[a]	1930-50[a]	1855-79	1880-04	1905-29[a]	1930-50[a]
Number of observations	5306	5306	5232	3335	5306	5306	5291	3335
Mean no. of deaths (± SD)	1.2(±1.2)	1.5(±1.3)	1.4(±1.3)	0.6(±0.9)	3.2(±2.1)	3.0(±1.9)	1.9(±1.7)	0.9(±1.1)
Heat								
day 0	0.0566**	0.0485**	0.0350*	-0.0068	0.0841**	0.0533**	0.0402**	-0.0075
lag-days 1-2	0.0509**	-0.0054	0.0460**	0.0066	0.0152	-0.0066	0.0429**	0.0622
lag days 3-6	0.0243	0.0362*	0.0178	0.0135	0.0164	0.0274**	0.0263	-0.0463
lag days 7-14	0.1066**	0.0867**	0.0417*	-0.0006	0.1245**	0.0656**	0.0662**	-0.0298
lag days 15-30	0.1366**	0.1167**	0.1351**	0.0991**	0.0700**	0.0944**	0.1549**	0.0335
Cold								
day 0	0.0017	-0.0135*	-0.0177**	-0.0299*	-0.0150**	-0.0216**	-0.0155**	-0.0149
lag-days 1-2	0.0149	0.0284**	0.0261**	0.0212	0.0185**	0.0241**	0.0075	0.0122
lag days 3-6	0.0122	0.0033	0.0000	0.0177	0.0087	0.0046	0.0148*	0.0319**
lag days 7-14	-0.0136*	-0.0094	-0.0068	0.0073	-0.0047	-0.0072	-0.0104	0.0003
lag days 15-30	-0.0189**	-0.0186**	-0.0419**	0.0379**	-0.0290**	-0.0131**	-0.0615**	0.0124
Seasonal trend	0.1843**	0.1195**	0.2896**	-0.1236*	0.1499**	0.0453**	0.2733**	-0.0323
α	0.0729**	0.0383**	0.1297**	0.4364**	0.0531**	0.0233**	0.1237**	0.2769**
R^2	0.2410	0.1850	0.2423	0.1743	0.3910	0.2471	0.3701	0.2235
R^2_α	0.4350	0.4026	0.2812	0.1628	0.5442	0.4970	0.4476	0.2440

a Except October-November 1918, May 1940-July 1945

b All models calculated with full model including seasonal time trend and temperature during different time lags

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

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

Tab. A-4a (continued). *Regression Coefficients of Negative binomial Regression between Daily infant Mortality and Temperature with Different Time Lags Controlled for Long-Term Mortality Trend and Season during all Summers and Winters per Province and Period*[a]

	Gelderland[b]				Zeeland[b]			
	1855-79	1880-04	1905-29[a]	1930-50[a]	1855-79	1880-04	1905-29[a]	1930-50[a]
Number of observations	5306	5306	5291	3335	5306	5306	5291	3335
Mean no. of deaths (± SD)	4.3(±2.5)	5.1(±2.7)	3.4(±2.5)	1.5(±1.4)	5.0(±3.4)	3.6(±2.7)	1.6(±1.7)	0.4(±0.7)
Heat								
day 0	0.0517**	0.0336**	0.0372**	0.0298*	0.0298**	0.0333**	0.0197	0.0103
lag-days 1-2	0.0189*	0.0206**	0.0433**	0.0063	0.0027	-0.0072	0.0077	0.0188
lag days 3-6	-0.0026	0.0160	0.0051	0.0009	0.0150	0.0321**	0.0299*	-0.0557
lag days 7-14	0.0642**	0.0819**	0.0565**	-0.0098	0.1046**	0.1106**	0.1021**	-0.0475
lag days 15-30	0.1019**	0.1137**	0.1755**	0.0868**	0.2050**	0.1873**	0.1990**	0.0504
Cold								
day 0	-0.0175**	-0.0202**	-0.0235**	-0.0139*	-0.0054	-0.0079	-0.0346**	-0.0126
lag-days 1-2	0.0221**	0.0235**	0.0188**	0.0082	0.0241**	0.0165*	0.0199*	0.0229
lag days 3-6	0.0097*	0.0125**	0.0125**	0.0296**	0.0190**	0.0119*	0.0211**	0.0170
lag days 7-14	-0.0052	0.0009	-0.0081	0.0025	-0.0098*	-0.0023	-0.0247**	0.0265
lag days 15-30	-0.0333**	-0.0055	-0.0524**	0.0195**	-0.0485**	-0.0329**	-0.0633**	-0.0040
Seasonal trend	0.1061**	-0.0162*	0.1571**	-0.0014	0.0644**	0.0903**	0.4794**	0.0135
α	0.0521**	0.0383**	0.1397**	0.0995**	0.0681**	0.1019**	0.1316**	0.2501**
R^2	0.3897	0.3659	0.4190	0.3211	0.6085	0.5169	0.5733	0.2189
R^2_α	0.4895	0.4820	0.3927	0.4755	0.6820	0.5543	0.7100	0.4373

a Except October-November 1918, May 1940-July 1945

b All models calculated with full model including seasonal time trend and temperature during different time lags

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

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

Tab. A-4b *Regression Coefficients of Negative Binomial Regression between Daily Mortality of the Population Aged 75+ and Temperature with Different Time Lags Controlled for Long-Term Mortality trend and Season during all Summers and Winters per Province and Period*[a]

	Drenthe[b]				Groningen[b]			
	1855-79	1880-04	1905-29[a]	1930-50[a]	1855-79	1880-04	1905-29[a]	1930-50[a]
Number of observations	5306	5306	5232	3335	5306	5306	5291	3335
Mean no. of deaths (± SD)	0.5(±0.8)	0.8(±1.0)	1.2(±1.2)	1.8(±1.6)	1.2(±1.2)	1.9(±1.7)	2.7(±2.0)	3.6(±2.3)
Heat								
day 0	0.0566**	0.0485**	0.0350*	-0.0068	0.0462*	0.0203	0.0402**	0.0084
lag-days 1-2	0.0509**	-0.0054	0.0460**	0.0066	0.0126	0.0151	0.0225	0.0371**
lag days 3-6	0.0243	0.0362*	0.0178	0.0135	0.0135	0.0161	0.0134	-0.0117
lag days 7-14	0.1066**	0.0867**	0.0417*	-0.0006	0.0198	0.0064	0.0027	0.0151
lag days 15-30	0.1366**	0.1167**	0.1351**	0.0991**	0.1324**	0.0402	0.0169	-0.0013
Cold								
day 0	0.0017	-0.0135*	-0.0177**	-0.0299*	-0.0060	-0.0092	-0.0039	-0.0215*
lag-days 1-2	0.0149	0.0284**	0.0261**	0.0212	0.0223**	0.0085	0.0061	0.0138*
lag days 3-6	0.0122	0.0033	0.0000	0.0177	0.0166**	0.0264**	0.0204**	0.0122*
lag days 7-14	-0.0136*	-0.0094	-0.0068	0.0073	0.0200**	0.0227**	0.0268**	0.0101*
lag days 15-30	-0.0189**	-0.0186**	-0.0419**	0.0379**	-0.0178**	0.0116*	0.0186**	0.0116*
Seasonal trend	0.1843**	0.1195**	0.2896**	-0.1236*	0.1068**	-0.0179	-0.0457**	0.0716**
α	0.0729**	0.0383**	0.1297**	0.4364**	0.0669**	0.0728**	0.0519**	0.0468**
R^2	0.2410	0.1850	0.2423	0.1743	0.3160	0.4362	0.4915	0.4434
R^2_α	0.4350	0.4026	0.2812	0.1628	0.5977	0.6649	0.7130	0.6308

a Except October-November 1918, May 1940-July 1945

b All models calculated with full model including seasonal time trend and temperature during different time lags

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

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

Tab. A-4b (continued) *Regression Coefficients of Negative Binomial Regression between Daily Mortality of the Population Aged 75+ and Temperature with Different Time Lags Controlled for Long-Term Mortality Trend and Season during all Summers and Winters per Province and Period*^{a}

	Gelderland^{b}				Zeeland^{b}			
	1855-79	1880-04	1905-29^{a}	1930-50^{a}	1855-79	1880-04	1905-29^{a}	1930-50^{a}
Number of observations	5306	5306	5291	3335	5306	5306	5291	3335
Mean no. of deaths (± SD)	2.0(±1.7)	2.7(±2.1)	3.8(±2.6)	5.1(±3.0)	0.8(±1.0)	1.4(±1.3)	1.9(±1.6)	2.3(±1.7)
Heat								
day 0	0.0225*	0.0228*	0.0497**	0.0234**	0.0492*	0.0089	0.0513**	0.0403**
lag-days 1-2	0.0109	0.0058	0.0140	0.0161	-0.0009	0.0220	-0.0084	0.0002
lag days 3-6	-0.0152	0.0033	0.0036	0.0128	-0.0317	-0.0363	-0.0065	-0.0073
lag days 7-14	0.0194	-0.0098	0.0080	-0.0118	-0.0101	0.0186	0.0117	0.0033
lag days 15-30	0.0019	0.0315*	0.0023	0.0027	0.1216**	0.0164	0.0161	-0.0023
Cold								
day 0	-0.0060	-0.0131**	-0.0104**	-0.0079*	-0.0040	-0.0125	-0.0055	-0.0122
lag-days 1-2	0.0139*	0.0204**	0.0129**	0.0011	0.0162	0.0334**	0.0087	0.0147
lag days 3-6	0.0221**	0.0157**	0.0228**	0.0155**	0.0286**	0.0082	0.0203**	0.0076
lag days 7-14	0.0211**	0.0194**	0.0196**	0.0086*	0.0347**	0.0199**	0.0340**	0.0132*
lag days 15-30	-0.0174**	0.0137**	0.0148**	0.0063	-0.0113	0.0181**	0.0077	0.0077
Seasonal trend	0.0489**	-0.0043	-0.0077	0.0571**	-0.1129**	-0.1631**	-0.0294**	0.1230**
α	0.0389**	0.0598**	0.0443**	0.0306**	0.0146	0.0516**	0.0483**	0.0408**
R^2	0.4543	0.4852	0.5446	0.5555	0.3340	0.3660	0.4196	0.4273
R^2_α	0.7820	0.6922	0.7381	0.7665	0.9126	0.6973	0.7121	0.7326

a Except October-November 1918, May 1940-July 1945

b All models calculated with full model including seasonal time trend and temperature during different time lags

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

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