Heat waves and cold spells and their effect on mortality: An analysis of micro-data for the Netherlands in the nineteenth and twentieth century

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Abstract

To gain insight into the changing impact of cold and heat on mortality, we analyze Dutch individual death records in relation to daily temperature for the period 1855-1950 for three 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 analyze the changes in the vulnerability to temperature fluctuations. Our study showed that between 1855 and 1950 total mortality underwent an immediate increase when temperature increased above the optimal value, the size of that effect being more or less the same in all three provinces. We observed increases in 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. 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 stronger felt among unskilled workers. Short-term delayed effects of heat as well as longer-term delayed effects declined from 1900 or 1930 on. The vulnerability of unskilled workers and infants to heat declined after 1930.

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1. Introduction

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 the August 2003 heat wave were published for many countries in Europe (for France, see for example 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'. It comes as no surprise that the 2003 heat wave led to an increased interest in the lethal consequences of high temperatures. Renewed interest one might say because until the first decades of the twentieth century summer peaks in mortality frequently attracted the attention of medical doctors and statisticians. From the 1920s on, infectious diseases, which were so prevalent among infants during the summer period, were brought under control. Winter cold from then on became the major seasonal factor affecting the death rate in temperate zones such as Western Europe. Studies documented that thousands of extra persons died in each winter season, when winters were extremely cold (Analitis et al., 2008; Baccini et al., 2008; Healy, 2003; Keatinge et al., 1997; McMichael et al., 2008).

The relation between extreme weather conditions and mortality and the changes therein over time are an interesting research topic for historians. How societies coped with environmental shocks such as extremely high temperatures and whether or not they were able to restrict its 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

2 We wish to thank the Gelders Archief (province of Gelderland), the Drents Archief (the province of Drenthe) and the Zeeuws Archief (province of Zeeland) for putting their data at our disposal.

– 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).

Although increases in summertime mortality during hot spells have been documented for historical populations by contemporaries, there have been few quantitative assessments of excess mortality during heat waves or cold spells, let alone studies in which the vulnerability of specific groups was analyzed. Historical studies of the relationship between extreme weather conditions and mortality as a rule are based on rather crude weather and mortality indicators. Mortality is mostly available only for the population as a whole, without a distinction by sex or age, and often only on an annual basis, whereas temperature data mostly are monthly averages (see for example Galloway, 1985; Galloway, 1986; Galloway, 1988; 1994; Landers, 1986; McDowall, 1981). An important drawback of such a monthly aggregation of mortality data is that it makes it almost impossible to identify properly 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 day) and may in part be due to short-term displacement: it is therefore highly likely that an effect of heat-related mortality is attenuated even in a weekly-aggregated analysis (Carson, Hajat, Armstrong, & Wilkinson, 2006). Historians rarely have access to information on daily numbers of death and daily temperature data and where that is the case these records were collected only for small communities and restricted time periods.

The number of studies in which over a long period of time with adequate methods and on the basis of comparable data the relation between extreme weather conditions and mortality is studied 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'. Although Rau was referring to the present-day situation, 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 in particular had on the poor, there is hardly an empirical study focusing on this aspect.

However, during the past decades historical databases with more detailed information on deaths have become available for a number of countries. In this paper we use data relating to three 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 that 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 almost completely disappeared 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 were responsible 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; maximum temperatures in the Netherlands only sporadically exceed 27° C, minimum temperatures are rarely below -10° C. As a consequence, the variation in temperature-related mortality in the Netherlands 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 as the Netherlands.

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

2. Medical doctors looking at heat waves and cold waves

In his *On Airs, Waters, And Places*, Hippocrates had stressed the role that weather conditions played for human health. ‘Whoever wishes to investigate medicine properly, should proceed thus: in the first place to consider the seasons of the year, and what effects each of them produces for they are not at all alike, but differ much from themselves in regard to their changes. Then the winds, the hot and the cold, especially such as are common to all countries, and then such as are peculiar to each locality’. For many centuries Hippocrates’ ideas were a source of inspiration for physicians and stimulated studies of the ways in which the natural conditions of a country affected the appearance and virulence of diseases. When empirical data on mortality became available, it is obvious that the effect that season and hot and cold temperatures had on mortality became a central topic of study of physicians, statisticians and hygienists.

In particular during periods of extreme heat or cold, Dutch doctors, but bureaucrats, journalists and ordinary people as well, pointed to the negative health effect that the weather conditions had. Nineteenth-and early twentieth-century literary sources, personal documents, articles in newspapers, iconographic sources, autobiographies and official reports bear witness of their worries.

In 1868 summer temperatures in the Netherlands reached extremely high levels. Doctors soon became aware of the lethal consequences that this had in particular on the death rates of infants. With the help of locally collected data they studied with rather primitive methods the unusual strong increase in infant mortality (Gedeputeerde Staten Zeeland, 1869; Godefroi, 1869). One of the leading Dutch hygienists, Casper Pieter Pous Koolhaas (1831-1893), stated that in 1868 in many places '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 was already in normal circumstances. Food stuffs such as milk and bread porridge underwent 'during hot weather a slight change, and in this process start to decay… To dilute the milk, or to prepare other foodstuff or drinks, water is used, and if one considers how poor in some places the water is as a consequence of the heat and drought, than one has another reason for the harms that in particular during hot summers are caused by artificial feeding of infants'. 'The poorer the water that one uses, and the sooner and broader the decay of the food, the higher is also 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 stronger 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 of 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, in particular in hot weather. The milk that is bought by those people for whom spending a few cents more is a question of high importance, will generally be poorer, than the one that can be supplied by those people who wish to buy good stuff, even if that costs some more; and those who buy the bad and often old milk, very often will have more trouble in trying to preserve it from decay' (Pous Koolhaas, 1869).

During extreme winters as well the effect on mortality was felt. The winter of 1890-1891 was extremely cold. A well-known Dutch author of regional novels Herman de Man (1898-1946) published in 1936 *De barre winter van negentig* (The barren winter of the nineties) in which he empathically described the way in which the poor were struck by the cold. 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. In the diary that the peat worker Hendrik Fennis van Dam kept during the years 1879-1935 he mentioned that the potatoes which he kept in his cellar had been frozen. 'I am afraid that people will freeze to death'. Bread on the table turned into a lump of ice. Wells could no longer be used. In particular the agrarian population, or more generally speaking, everybody whose professional activities were largely dependent of the weather, suffered from the dreadful nature. It was mainly the poor that suffered. Many people, mostly very old ones and children, were arrested for begging. To support the poor and widows, in numerous villages and towns speed skating competitions were organized for the poor, widows or destitute workers, where hundreds of people competed for foodstuffs, fuel and clothes. Children died in prams while touring around with their mother, others died in their bed-stead (De Jong, 1990, 77-79). An anonymous letter to the editor of a local newspaper (*Het Nieuwsblad*) on Januari 10 1891 described the situation in a region called the Hoeksche Waard, an island a little bit to the 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 of our destitute human beings. (…) Go and visit our poor, and abide a few moments at the bedside of the numbed old people, look at the chilly, shivering children, covered with rags, yearning for 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 that are less well off than animals in the cowshed; people that 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).

In the first decade of the twentieth century, several empirical studies were published on the relation between seasonal temperature fluctuations and infant mortality. Saltet and Falkenburg (1907) published a detailed study on the summer excess of infant mortality, making use of monthly data for all provinces, separately for town and countryside, for the period 1881-1905. With the help of graphical presentations they tried to show that during this period the height of the temperature did not run parallel to the level of infant mortality; in stead, it were the *fluctuations* of the temperature that were responsible for the excess summer mortality. The highest summer excess was observed in the province of Zeeland. They also found that over time the height of the summer peaks had increased and that summer peaks were found earlier in the year in the towns than in the countryside. Saltet and Falkenburg's conclusion that no association could be observed between temperature and infant mortality was disputed by the climatologist Van Everdingen (1907). He argued that there was no directly linear relation between fluctuations in temperature and in infant mortality but that mortality increased only when a certain temperature limit was exceeded. In stead of using average temperatures Van Everdingen related the mortality fluctuations to the number of days above a certain maximum temperature, taking a lag time into account.

When in 1911 the Netherlands, like other countries in Europe, were struck by a heat wave the death toll was 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, less so in the larger towns "with their good drinking water, and controlled milk stations", in these terms the Dutch press described in November 1911 the effect of the heat wave ("De statistiek van den loop der bevolking," 1911) Medical doctors studied in detail its consequences for infant health. In The Hague a survey had been set up in which all children born in that city in 1908 were followed for some years. 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 not only for children aged one month or more mortality during the 1911 heat wave increased; during the first month of life death risks increased as well, although less than was the case for older children. Contrary to the expectation, gastro-intestinal diseases were the most important factor behind the increased summer mortality of these young (less than one month) children as well. 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 made clear that a relatively high number of infant deaths took place within one or two days after the child had fallen ill. The start of the illness could thus be located in one of the days with high temperature. In other cases a more lasting and long-term effect of periods of high temperature was visible as several weeks of illness had preceded the death of the child. During the first heat period on average 10-12 days elapsed between the heat peak and the mortality peak; as the heat period kept up or temperatures rose further, the lag period shortened and in the end lasted only 1-2 days. Among children that in the heat period died due to gastro-intestinal diseases, the artificially-fed children were disproportionally present.

Heynsius van den Berg (1912), a medical doctor practising in Amsterdam, compared the ways in which infants in some of the larger Dutch towns had endured the heat period of 1911. Making use of weekly data on the numbers of infant deaths, he detected that the larger cities had withstood the summer relatively well. He explained this by the hygienic measures that had been taken there in the recent past. Whereas the highest temperatures were measured in July, the highest levels in infant mortality were observed in August, after a series of hot days. This suggested that there was no direct adverse effect of heat on infants; it was only after a series of days with extreme high temperatures that not only outdoor but also indoor temperatures reached such high levels that the situation for infant became unbearable

The paediatrician Cornelia de Lange studied the 1911 heat wave with Amsterdam data. The daily course of mortality due to feeding disorders and convulsions was graphically related to daily temperatures. De Lange observed a clear relationship between heat and mortality; in general the increase in mortality followed the increase in temperature. In September when the heat had already disappeared but the houses were still overheated high mortality peaks could still be found. Parents of deceased children were interviewed and asked about the feeding of the children, the progress of the illness, the housing quality, the place where the child stayed during day- and night-time, and the place where the cooking and the laundry was done. De Lange observed that the heat had less effect on children younger than one month. She explained this by the fact that very young children had a relatively high heat loss and that many of these children were still breastfed. A large part of the deceased children had lived in single-room dwellings and very often the cooking and laundry was done in the room where the infant stayed during daytime. Several times mention was made that the child slept with the mother in one bed, often in an alcove. De Lange stressed the role of the indoor climate; even when the outdoor temperature had decreased, the temperature in the place where the child stayed could remain very high for quite some time. The situation was even more adverse when rooms were full of water vapour generated during laundry and cooking. A further problem was that in periods of extreme heat the infant became thirsty; the resulting restlessness was not fought with water but with solid food or often sour milk. And, finally, many infants were dressed in an excessive of clothes (De Lange, 1913). An interesting observation was that in rural areas flees played an important role in the transmission of gastro-intestinal diseases. Flees were present in much higher numbers in September, and therefore it was not heat only that played a part in the high infant mortality in the summer (Wybrands, 1914, 75-76).

When in the twentieth century epidemic diseases lost their weight and infant and childhood deaths became rare occurrences, the interest in the effect of hot summers waned. Looking back on his father's practice as a rural general practitioner in the beginning of the twentieth century, the Dutch medical doctor Verbeeck wrote: 'More so than nowadays the professional practice, and in particular the rural one, knew seasons. There was the end of the Winter, a time during which many older people died. In particular when the Winter had been severe and Spring was long in coming there were always some old persons, of which my father said: 'I wonder whether he will make it'. It were especially men that went under. Old women still did some work around the farm: lulling a child, peeling potatoes, collecting eggs and things like that. But the men: in stead of strolling around the farm with their stick and pipe, like they did in Summer, mumbling their comments on everything, the old peasants were dazing by the fire. Many a person there literally felt in his last sleep. The heating in the farmhouses was moderate. Bedrooms were not heated at all. And when the sun did not return in time, many older persons lost the fun in their worldly life' (Verbeeck, 1985, 36).

The studies mentioned above provide a very insightful picture of the devastating effect of heat and cold. They are not very well suited however to make quantitative estimates of those effects. Whenever they used statistical methods, these were rather crude and mainly of a descriptive character. None of the studies empirically addressed issues such as differences in vulnerability by age, sex, or social class nor did they analyze whether over time there were changes in the degree in which populations were affected by winter or summer temperature excesses. By combining detailed mortality and temperature data with advanced time-series methods we hope to be able to shed new light on the effects that heat waves and cold spells in the past had on mortality.

3 Mechanisms in weather-related mortality

In a large number of studies overviews have been given of the factors that in contemporary societies account for an increase in mortality due to cold or heat. 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 of the heat-related deaths are due to hyperthermia, overheating of the body. Cold-related death are mainly caused by coronary and cerebral thrombosis and respiratory diseases whereas coronary and cerebral 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*. Falls in temperature in winter are closely followed by increased mortality, with characteristic time courses for different causes of death. For heat periods as well, immediate effects (for instance acute myocardial infection) 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 in which the temperature is extreme (Huynen, Martens, Schram, Weijenberg, & Kunst, 2001). Main heat effects are usually visible on the current day or last perhaps another day or two (Pattenden, Nikiforov, & Armstrong, 2003). *Compensatory effects on mortality* might be registered

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

when longer time periods are studied. The number of deaths caused by heat during heat waves is often assumed to be compensated for by a fall in numbers of deaths in subsequent weeks. The suggestion is that heat mainly has an effect on people whose health is already impaired and who would have died within a short time anyway. This compensating effect is known as 'harvesting' effect (Huynen et al., 2001). The effects of heat and cold might also be dependent on *the sudden occurrence of a change in temperature*. The effects of heat and cold depend on whether populations have had the chance to adapt themselves to extreme weather conditions (Ballester, Michelozzi, & Iniguez, 2003). The 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 (1979-87) showed that hazardous weather situations could be identified almost as accurately by temperature as by an index that also included wind-chill (Kunst, Groenhof, & Mackenbach, 1994). The effect of high and low temperatures also depends on *the climatological situation of the region* studied. Studies of populations living in widely different climates show that they have adjusted to their own climate remarkable effectively over time. This applies to cold as well as to hot regions (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. In temperate regions, winter was a more dangerous period at the beginning of life than summer, although clothes, heating and good housing could reduce its effects. In warmer regions, the effects of winter were much stronger.

It is important to stress that the temperature-mortality relationship might be due to *other mechanisms 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 for man's survival, such as the growth of foodplants and animals, and on the physical environment, such as flooding and storm. These direct effects could lead to second-order effects on mortality (Michaelowa, 2001). Relevant is also the relationship 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 which 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 and diarrhoea and other gastric diseases. The last group of diseases affected in particular those children who had lost the protection of the mother's milk (Oris et al., 2004).

4 Vulnerable groups

In studies dealing with present-day effects of extreme weather on mortally, a significant variation in effect of heat and cold is observed according to age. The decrease in thermoregulatory function and appreciation of cold and heat with increasing age is the main reason why the elderly are disproportionally affected by extreme weather conditions (Hajat, Kovats, & Lachowycz, 2007). Infant and childhood deaths now make up only a small fraction of the total number of deaths and it is therefore understandable that recent studies have rarely focused on the effects of variation in temperature on infant mortality (an exception is Hare, Moran, & Macfarlane, 1981). There is no evidence of excess mortality attributable to heat waves in children in present-day studies (Kovats & Kristie, 2006) and only rarely mention is made of the effect that extreme cold had on the death risks in this age group.

The determination of which gender is more susceptible to weather fluctuations is much in dispute. In studies of England and 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). Again, the question is whether these differences in vulnerability between the sexes are also observed in a situation in which death was for a large part a phenomenon that was linked to very young age groups.

Relatively few studies have examined the variation in temperature vulnerability by socioeconomic position and the few studies often gave 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 risks of heat-related deaths during the 1995 Chicago heat wave among those with low incomes whereas Kaiser et al. (2007) found the same effect among low-educated people. 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 in England and Wales in 1998-2000 that cold-related mortality in men of working age was low in unskilled occupations but it was high in men of retired ages in that same social class. The beneficial effect of work-related factors in this social class was explained by internal heat production from manual work, offering protection against daytime cold stress. 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 the period 1980-98, using a variety of socio-economic indicators. He did not observe a relationship between excess winter mortality among people aged 65 years or older and factors such as level of education, wealth, and housing conditions. This was explained by the strong homogeneity of the Danish population, a homogeneity that is also at a very high level. Area studies gave conflicting results as well. A study for the period 1993-2003 in the UK (Hajat et al., 2007) observed very little differences in heat effects according to the level of deprivation of the neighbourhood and no relationship of cold with deprivation. The results of a study of the French 2003 heat wave however point to the most deprived populations being more vulnerable to heat waves than the least deprived ones (Rey et al., 2009). It remains to be seen whether in the nineteenth and early twentieth century such a difference in vulnerability can be observed as well.

5. The study regions

Nation-wide and compulsory birth and death registration according to the rules led out in the Code Napoleon was introduced in the Netherlands in 1811, at the time of the incorporation of the Netherlands into the French Empire. During the past decades, in the provincial archives in the Netherlands dozens of volunteers and staff have started to enter death records into a database within the framework of projects called ISIS and GENLIAS. The intention of these projects is to build up 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) on until the date these data are no longer in the public domain. Death records enter the public domain after 50 years. We were able to use data for three of the eleven provinces of the Netherlands: the provinces of Zeeland, Drenthe and Gelderland.[4] Figure 1 gives an overview of the location of the selected provinces.

<< Figure 1. Map of the selected Dutch provinces around 1900 >>

The three selected 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 waste land covered with heath and some woods, ill adapted for cultivation and having 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 in the eastern parts. Small regional market places and several larger towns such as Arnhem and Nijmegen hosted industrial activities and administrative services. Farms in Gelderland were relatively small, the infrastructure less

4 Data for Gelderland at this moment cover only municipalities of which the name starts with the letters A to V, and relate to 75 percent of the total number of deaths in the province.

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 is bounded in the East by 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. On the sand-grounds sheep and cattle were reared and forest cultivated. In connection with the cultivation of potatoes, factories were established for making spirits, straw-paper etc. The people of Drenthe have had a long history of poverty. The poor agricultural soil frequently did not yield enough to prevent the 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 middle of 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 every other province in the Netherlands. There were few centers of any importance and population density was rather low.

Zeeland forms the south-western 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. Zeeland was for a long time a rural area of which the towns of Middelburg and Vlissingen were the administrative and industrial centers. Grain-farming on the sea-clay was the dominant economic activity (60 per cent of the labor force was involved in agriculture). Part of the population was involved in the fishing industry. In the second half of the nineteenth century agricultural modernization was eroding the position of the farm laborers. The economy of the region started to change after 1900 when industrialization took place (Priester, 1998; Wintle, 1985).

Mortality levels in the three provinces differed considerably. Whereas Zeeland like the other Dutch coastal and low-lying areas was characterized by very high mortality until late in the nineteenth century, in particular by very high infant mortality, reaching levels of 350 deaths before age one per thousand live births, Drenthe and Gelderland were much better off. As Table 1 shows, the expectation of life at birth in Zeeland was until the middle of the nineteenth century much lower than elsewhere. It was only in the last decades of the nineteenth century that Zeeland reached higher values of life expectancy.

< < Table 1 around here > >

Together, the three regions cover a large part of the economic, demographic and cultural landscape of nineteenth-century Netherlands.

The climatological conditions in the three regions differed slightly. The average annual temperature in Zeeland was usually a little bit higher than in any other part of the country, due to its bordering to the North Sea and the higher number of hours of sunshine. In particular the average minimum temperature was higher in Zeeland than in other parts of the Netherlands. Minimum temperatures below minus 10 degree Celcius were rare in the province, in particular in the most western part. In Gelderland however, and even more so in Drenthe, temperatures were more extreme. Minimum temperatures reached much lower values and maximum temperatures were higher there as well. The average number of frost days (minimum below 0 degrees) in the north-eastern province was much higher than in Gelderland and Zeeland (Heijboer & Nellestijn, 2002).

6. Weather and mortality data

From the beginning of the 1850s, at different weather stations in the Netherlands readings of the temperature were taken. Weather stations were among other places located in the provinces of Zeeland, (in the city of Vlissingen), Groningen (city of Groningen, later in nearby Eelde in the province of Drenthe), and in the province of Utrecht (city of Utrecht, later De Bilt).[5] Within the framework of the E.C. Climatological Research Programme the Royal Netherlands Meteorological Institute (KNMI) started research on historical instrumental observations of the weather in the Netherlands, at the beginning of the year

5 From 1 November 1896 till 1 December 1898 weather measurements took place in the city of Utrecht as well as in De Bilt to determine the local differences and to make it possible to link the two series of measurements.

2000. The objective of that program, called 'HISKLIM' (HIStorical CLIMate), is to make historical meteorological observations from sources in the Dutch language available in a digitized form (see KNMI, 2009).

The weather measurements in the nineteenth century took place with self-recording apparatus with a moderate degree of reliability. Due to changes in the number of times readings were taken, in the time at which the readings took place, in measuring position, measuring instruments, etc. the climate time series are not homogeneous.[6] To increase the usefulness of the climate time series, the data for daily mean temperature and maximum and minimum temperature 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 till 1950. Given the differences between the three provinces in the climatological conditions we decided not to use one single temperature series for all three regions but to apply region-specific measurements. For Zeeland we used the data from the Vlissingen weather station, for Gelderland those of the Utrecht/De Bilt weather station, and for Drenthe those of the Groningen/Eelde weather station.[7] The weather station of Utrecht was in use until 1897,

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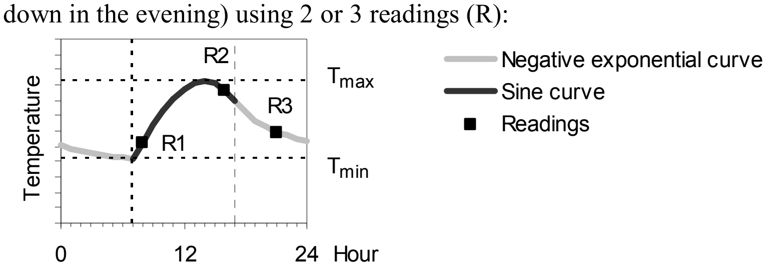
6 For observations relating to the period before the 1880s, the times of observation were not standardized. For the Vlissingen station for example, temperature (in degrees Celcius) was measured from December 1, 1854 on, at 9.00, 12.00, and 15.00 hours. From October 7 1855 on, minimum and maximum temperatures were recorded. From December 1 1857, temperature measurements took place at 8.00, 12.00 and 15.00 hours, from April 1, 1859 on 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.

7 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 temperature rise in the morning and afternoon cooling down) and a negative exponential curve (for cooling down in the evening and at night) with parameters estimated by Van Engelen and Geurts (1983) (for time of minimum and maximum temperature, times of sunrise and sunset and tempo of cooling down in the evening) using 2 or 3 readings (R):



and was then replaced by the station of De Bilt, around three kilometres removed from the earlier station. The Groningen station was in use until 1906 and then replaced by a station in Eelde, seven kilometres away from Groningen. 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 (Vlissingen) and any of the municipalities in that province for which we had mortality data was 45.9 km; for Gelderland the largest distance between the weather station of Utrecht/De Bilt and any of the municipalities in Gelderland was 109.2, respectively 106.7 km; the largest distance between the Groningen/Eelde weather station and any municipality in Drenthe was 63.0, respectively 56.8 km.[8]

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 having somewhat higher temperatures than Drenthe and Gelderland. Extremes were however much more frequent in the last two provinces. Both the number of tropical days (with a maximum temperature higher than 30° C) and the number of ice days (with a maximum temperature lower than 0° C) were much higher in Drenthe and Gelderland than in Zeeland. The 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[9] and heat values[10]. The Hellmann value was much higher in Drenthe and Gelderland than in Zeeland whereas the mean heat value was higher in Gelderland than in Zeeland whereas Drenthe had the smallest number.

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 of which has a maximum temperature of at least 25° C (so-called summer days), including at least three days with a maximum temperature of at least 30° C (so-called tropical days) measured at the De Bilt station located in the centre of the Netherlands. Applying this definition to the

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8 In the following we refer to weather stations as if they are located in the province for which we have mortality data.

9 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 minus sign.

10 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.

weather stations in our study, there were only four heat waves in Zeeland in the period 1855-1950 against 18 in Drenthe and 27 in Gelderland. According to the definition by the Royal Netherlands Meteorological Institute 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). According to this definition, there were eight cold spells in Zeeland against 31 in Drenthe and 33 in Gelderland.

Mortality data for the three provinces are available for the period 1812-1950. We recoded ages at death into age groups, and the occupation of the deceased, of his or her parents and of her spouse, in case where this applied, into social classes.

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

We classified all occupations of deceased persons, of their grooms, and their fathers and mothers 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 Organisation's *International Standard Classification of Occupations* (ISCO68) scheme. These historical occupational titles were classified according to a social class scheme recently proposed by Van de Putte and Miles (2005), known as the Social Power (SOCPO) scheme. Social power is defined as the potential to influence one's 'life chances' through control of (scarce) resources and is based on economic (based on factors such as 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. In level five are included executives, having general policy tasks, supra-local businessmen, non-manual super-skilled and members of the nobility. In level four are the supervisors of skilled workers, local businessmen, manual super skilled and non-manual skilled people. Level three includes supervisors of semi- and unskilled workers, and manual skilled workers. In level two are the self-employed who are locally oriented and have a minimal capital and the semi-skilled workers. Level one comprises the unskilled workers. We denote these groups as respectively the elite, the middle class, the skilled workers, the semi-skilled workers, and the unskilled workers. In view of the specific position occupied by farmers in contemporary social class mortality studies we excluded them from the middle class and placed them in a separate category. Given the small numbers we ultimately have grouped together the elite with the middle class in one group. A large part of the deceased could not be placed in one of these categories as they were no longer economically active at the time of their death.

Table 2 presents descriptive statistics for the mortality and temperature variables by 25-year period and province. The total number of deaths in the database was 1,361,572, ranging from 382,900 in the period 1855-1879 to 272,700 in the period 1930-1955. Around 19 per cent of all deaths concerned infant mortality (below the age of one year) and around 41 per cent people aged 50 years or older. The percentage of infant deaths was much higher on Zeeland, not unexpectedly given Zeeland's much higher infant mortality. The distribution of deaths by age group showed a shift from younger to older age groups. In the first two periods around 24% of all deaths concerned mortality below the age of one year whereas in the most recent period that percentage had dropped to less than eight per cent. The share of the oldest age groups, 50 years and older, in total mortality increased from 29 to more than 63%. The distribution by social class shows that a large majority of the deaths belonged to the labouring classes: unskilled and semi-skilled workers in and outside agriculture together constituted around 33 per cent of all deaths, and skilled workers almost ten per cent. Almost 13 per cent of the deaths were from a family working as a farmer. Upper and middle classes made up ten per cent of the total. In all provinces the percentage of deaths belonging to the labouring unskilled and semi-skilled workers in and outside agriculture decreased considerably over time. That was also the case with farmers. At the same time there was in particular in the most recent period an enormous increase of the number of deaths with social class unknown (that is, either unknown or no occupation given, particular in the case of women).

7. Method

We use statistical modelling to study the relationship between extreme temperatures and mortality. The approach that 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 period 1979-1997 (Huynen et al., 2001) and in the Dutch province of Zeeland during the period 1855-2006 (Ekamper, Van Poppel, Van Duin, & Garssen, In press). 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 so-called count data (the number of deaths) we thus need to use a Poisson regression. Poisson regression assumes the mean of the dependent variable (the mean number of deaths) to be equal to the variance of that dependent variable. However, in our case the observed variance of the dependent variables (total numbers of deaths, the number of deaths in selected age groups and social classes) is in general greater than the mean of the dependent variables. This is known as overdispersion. To account for overdispersion of our dependent variables we need to use a special case of Poisson regression, viz. 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 the long-term time trend and seasonal pattern.[11] In the analyses the *winter*

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11 The time span covers some periods with exceptional high mortality, viz. the Spanish flu pandemic in 1918 and the Second World War, (May 1940 to May 1945). However, no temperature measurements are

period includes the coldest months in the Netherlands: December, January and February. As many studies have shown, seasonality is changing over time both in the Netherlands (Kunst, Looman, & Mackenbach, 1991) and other countries (see for example 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 $t = 1,\ldots,T$ and $\omega = 2\pi/p$ (where p is the period, in our analyses the number of days per year). The smooth long-term time trend υ_t to account for long-term trends resulting from changes in for example population size and structure, and socioeconomic and health care conditions 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 three provinces separately.

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

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available from the Eelde and Vlissingen stations for the period of October 1944 to July 1945. Both the periods with exceptional high mortality and the periods with missing temperature data were excluded from the regression analyses.

average temperature was higher than the optimum value, otherwise optimum value minus average temperature).[12] The optimum value corresponds to the average value of the temperature with the lowest mortality level found by Huynen et al., for the Netherlands, viz. 16.5° C.

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

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

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) is 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, s_i (seasonality) is the sequential value of the long-term seasonal trend for day i estimated beforehand by the Gampe-Rau model. $\beta_0 \ldots \beta_j$ are the regression coefficients.

Negative binomial regression analyses were applied to both the average daily total number of deaths as well as to the average daily number of deaths by sex, age group (< 1 year, 1-4 years, 5-19 years, 20-49 years, 50-74 years, and 75 years or older) and social class (unskilled workers, semi-skilled workers, skilled workers, farmers, and middle class and elite) in years with heat waves and cold spells. Additionally, negative binomial regression analyses with respect to the 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. All analyses were conducted using Stata version 10 (StataCorp., 2007).

12 This is in line with the method used by the climatologist Van Everdingen who argued that there was no directly linear relation between fluctuations in temperature and in infant mortality but that mortality increased only when a certain temperature limit was exceeded. In stead of using average temperatures (Van Everdingen Jr 1907).

8. 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 in specific years. For that purpose 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 section 6). To be able to select years with extreme heat and cold in the same year in all three 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 were on average ranking the highest when combining the rankings of the three stations[13]. We selected the following four summers with extreme heat: 1868 (ranking 2nd), 1884 (4th), 1911 (3rd) and 1947 (1st); and the following four winters with extreme cold: 1854-55 (2nd), 1890-91 (3rd), 1928-29 (4th) and 1946-47 (1st). Table 3 gives some information about the selected years. In all stations the summer of 1947 had by far the highest heat value, with the summer of 1911 coming next (the Utrecht station being an exception). At the Utrecht station, 1947 even counted four heat waves. The winter period of 1946-47 was by far the coldest at all stations with the cold value higher than in any other year.

< < Table 3 around here > >

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 for the three provinces in years characterized by heat waves, whereas Figure 3 does the same for years characterised by cold spells.

As has been 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

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

example, in Zeeland, after a first heat wave starting around July 20 mortality started to increase after one week. Temperature peaks around July 29 and August 11 were again followed by mortality peaks on August 11 and 22. Both the average temperatures for lag days 7-14 and 15-30 showed 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 heat waves had on mortality. The summer of 1868 in all three provinces 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 pattern in Gelderland and Drenthe almost unaffected. The famous summer of 1911 again mainly had an effect on mortality ratios in Zeeland and Gelderland but in Drenthe an effect was not observed. Finally, the summer of 1947, with that of 1911 the hottest ones since the time weather data were registered in the Netherlands, left no trace on the mortality ratio of the three provinces.

< < Figure 2 about here > >

Figure 3 shows mortality and temperature in the coldest winters (the months December to February) in the period 1855-1950. Again we find here rather different reactions according to year and province. For example, during the winter of 1854-55 strong effects were found in Zeeland 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, again mortality ratios in Zeeland responded directly to the temperature decrease as did, to a lesser degree, those in Gelderland but in Drenthe no reaction whatsoever was found. The winter of 1928-29 did lead to a strong increase in mortality in all three provinces with Drenthe and Gelderland experiencing more than two times the normal expected numbers of deaths per day. The winter of 1946-47 did not provoke outspoken mortality peaks in any of the three provinces.

< < Figure 3 about here > >

Figures such as those presented above leave a lot of room for different interpretations of the relationship between temperature and mortality. They cannot take into account the effect of seasonality as such, net of that of above-optimal temperatures, nor do they allow to reckon 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 the problems mentioned above. They allow us to take a real step forward compared to the mainly descriptive statistical analyses presented by the contemporary medical doctors and statisticians.

Tables 4, 5 and 6 present the results of the regression model explained in section 7. Table 4 presents the regression coefficients of the model applied to all years with either a heat wave or a cold spell (as defined in section 6) whereas tables 5 and 6 do the same for all summers and winters. In table 3 the model was applied to total mortality (total number of deaths per day), numbers of deaths by sex, numbers of deaths by age group and numbers of deaths by social class. All models were calculated with the full model including seasonal time trend.

The general relationship between mortality and temperature can be judged by the ordinary r^2, and, in case there is question of overdispersion, by the overdispersion-based r^2.[14] The model fits the Zeeland data much better than that of Gelderland and even more so than the data for Drenthe. Furthermore, models fit much better the temperature mortality relation among the elderly than among infants, children and adults, but Zeeland is an exception to this rule; here, the models reaches the highest values of r^2 for infants.

The regression coefficients for heat with respect to total mortality show a significant positive instantaneous effect of heat in all three provinces. The size of that effect is more or less the same in the three provinces: the 0.0372 effect of heat for day 0

14 Since the statistical package we used does not produce a proper r^2 measure for negative binomial regression models, we use an ordinary squared multiple correlation coefficient with respect to the observed dependent variable and estimated values. Cameron and Windmeijer (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". However, they 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 overdisperion based r^2_α developed for negative binomial models (Miaou, 1996; Miaou, Lu, & Lum, 1996). $r^2_\alpha = 1 - (\alpha / \alpha_{max})$, with α_{max} estimated from a negative binomial model with a constant term and overdispersion parameter only. A smaller overdispersion parameter signifies a better fit.

in Drenthe means that a 1° C increase in temperature above the optimum temperature is associated with a 3.79% increase in the daily number of deaths.[15] For Gelderland and Zeeland the increase was respectively 3.01 and 4.07 percent. A statistical significant delayed effect of heat was also observed in all three provinces for lag-days 1-2; with respectively 1.78, 1.36 and 2.72 percent increases in the daily number of deaths for every 1° C increase in temperature above the optimum temperature the size of that effect was lower than the immediate one. Delayed and significant effects were in al three provinces also observed for longer lags, except for the not significant coefficient for lag-days 3-6. The effect of heat for the lag-days 7-14 and 15-30 varied from 1.43 and 2.30 percent in Drenthe, to 1.89 and 3.20 percent in Gelderland and 3.12 and 8.49 percent in Zeeland. During cold spells the regression models showed negative effects for the immediate temperature change but these were only significant in Drenthe and Gelderland, where a 1° C decrease in temperature below the optimum temperature caused a less than 1 percent decrease in daily mortality. In Drenthe and Gelderland there were significant delayed effects of temperature changes for lag-days 1-2, and 7-14 as well, leading to 1.32 and 0.83 percent (Drenthe) and 1.15 and 0.52 percent increases in daily mortality. In general the effects of heat were thus much stronger than those of cold.

In all provinces, the pattern appeared to be similar for men and women.

For most age groups the relationships 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, with in most cases 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 over suffered from strongly increased effects on the death ratios in Drenthe but not in 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 only visible in Gelderland, 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

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

effects were observed in Gelderland and Zeeland. Delayed effects in the expected direction for lag days 1-2 were visible in Gelderland and Drenthe for infants and the elderly, but not in Zeeland. For longer lags (7 days or more) elderly people in the provinces of Drenthe and Gelderland were undergoing mortality-increasing effects.

Table 4 also shows that the strength of the relationship between temperature and mortality varied by social class. In all three provinces there were immediate effects of heat visible and exception made only for unskilled workers in Drenthe these effects concerned the unskilled workers. In Zeeland, unskilled workers were the only affected group whereas in Gelderland and Drenthe almost all social classes underwent a direct effect of exceptional heat. In these last two provinces the effects were felt strongest among workers, in particular among the unskilled ones. Delayed effects of heat were absent in Drenthe. In Gelderland and Zeeland however delayed effects with lag days 7-14 and in particular lag-days 15-30 were present in al social classes and were extremely strong for the unskilled. For example, for unskilled workers in Gelderland, the daily number of deaths increased with 6.18 percent for every 1° C increase in temperature above the optimum temperature during the 15-30 days before the date of death; in Zeeland, the comparable percentage for the unskilled was even 15.0 percent, but in other social classes increases of 10-12 percent were observed as well.

Immediate mortality-increasing cold effects were absent in all social classes in all provinces but in Gelderland small but significant mortality-decreasing effects were observed among people of all social classes. 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 the unskilled workers.

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

< < Table 4 about here > >

Table 5 presents the regression coefficients of the regression model applied to all summers and winters in the period 1855-1950. Models were estimated separately for four

25-year periods, to analyse changes in vulnerability to heat and cold over time. As in some of these time periods in particular Zeeland did experience no or very few heat waves or cold spells we were only able to study the temperature mortality relation 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 have become stronger over time.

The results indicate that the immediate effect of heat in all provinces is significant and rather strong all over the period. Yet the strength of the effect is not constant over time and a clear trend is not visible either. Whereas in Drenthe the effect is clearly lower after 1930 than in any of the earlier periods for which data are available, in Drenthe and Gelderland the effects are as strong after 1930 as they were in 1855-79.

Short-term delayed effects of heat (days 1-2) were absent in all periods in Zeeland but in Gelderland and Drenthe they existed in most periods. Roughly speaking one could say that in these two provinces in the most recent period these effects have declined compared to earlier periods. Again the longer-term delayed effects of heat (lag days 7 and more) are rather strong in all provinces. Although the exact time course differs a little bit in the various provinces, it is absolutely clear that the delayed effect of heat has declined in the course of time, in particular after 1930. This applied to Drenthe, Gelderland and Zeeland. 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 period: whereas in 1855-79 a one degree Celsius increase above the optimum during lag days 15-30 implied a 5.5% (Drenthe), 4.1% (Gelderland) and 14.0 % (Zeeland) increase of the number of deaths per day the delayed effect of heat declined after 1930 to 1.0 % (Drenthe), -0.2% (Gelderland) and 0.1% (Zeeland).

The direct effect of cold is in all provinces and periods negative, implying that temperatures below the optimal lead to a decline in daily mortality. That effect is significant over the periods and provinces and only is absent in the most recent period in Zeeland. Results that are more in line with the expectations are observed for delayed effects. In all provinces significant mortality-increasing effects are found of below-optimal temperatures during lag-days 1-2, and in all provinces that effect has disappeared after 1929. 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.

Table 5 also allows us to find out whether in the course of time there was a change in the vulnerability to extreme temperatures by social class. To that end we studied how in each period of time the effects of temperature affected the unskilled workers and the farmers.

For unskilled workers we observe significant and rather strong immediate effects of above optimal temperatures on daily mortality in all provinces. In Drenthe and Zeeland that effect has disappeared after 1930, whereas in Gelderland one finds after 1930 an even stronger effect than before that time. Strong longer-time delayed effects (lag days 7-14 and 15-30) are present in all provinces until 1930 but these effects have disappeared after 1930 in all provinces.

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

In all provinces there is a mortality reducing immediate effect of cold below the optimal 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 5 about here > >

Table 6 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 10.5 to 2.5 whereas the number of deaths among people aged 75 and over increased from 4.0 to 7.8. Infant mortality underwent strong immediate effects of heat in every province and almost every period. It is clearly visible that the immediate effect of heat on mortality in the youngest age group is almost continuously decreasing over time in all three provinces. After 1930 it is only present in Gelderland. Similar tendencies are visible as far as the delayed effects of heat are concerned. 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 1855-79 a one degree Celsius increase above the optimum during lag days 15-30 implied a 14.6% (Drenthe), 10.7% (Gelderland) and 22.7 % (Zeeland) increase of the number of deaths per day the delayed effect of heat declined after 1930 to 10.4 % (Drenthe), 9.1 (Gelderland) and 5.2% (Zeeland).

For cold the immediate effects again were in the unexpected direction and were present in all provinces and periods. Delayed effects, in the sense of mortality increasing effects, were visible for lag days 1-2 in almost provinces but were absent after 1930.

In 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 on more or less the same level in the other two provinces. Strong delayed effects for lag days 7-14 and 15-30 were present in Drenthe but absent in other provinces.

Cold had no direct mortality-increasing effects for the elderly. Short-term delayed effects were observed until 1930 whereas in Zeeland and Gelderland also longer-term delayed effects (lag days 7-14 and 15-30) were observed. A clear time trend was not visible however.

< < Table 6 about here > >

9. Conclusion and Discussion

Our analysis is to our knowledge the first one in which for a long historical period the relationship between temperature and mortality was tested with rigorous statistical methods on the basis of 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 that far that it made our results untrustworthy. One might also question whether the choice of the optimum temperature was optimal; 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 use so far in present-day studies is however so small that we do not think that 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 increased above the optimal value, the size of that effect being more or less the same in all three provinces. We also observed increases in 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. The 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 as well. 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 stronger felt among unskilled workers whereas also delayed effects with lag days 7-14 and 15-30 were extremely strong for the unskilled workers. All in all, the relationship between cold spells and mortality appeared to be much weaker than the relationship 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 a clear trend was not visible. Short-term delayed effects of heat as well as longer-term delayed effects declined from 1900 or 1930 on. Mortality-increasing effects were found of below-optimal temperatures during lag-days 1-2, and this effect disappeared after 1930 as well. The vulnerability of unskilled workers to heat declined after 1930, and that related to the immediate as well as to the 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.

Our study corroborates in a rigorous way many of the conclusions based on much more simple methods made by contemporaries about the relationship between temperature and mortality.

For example, our study confirms the outcomes of the 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. For unskilled workers, the strongest direct and delayed effects of heat were found.

We also observed strong regional differences in the effect of heat on mortality. In particular the province of Zeeland was enduring strongly increased death rates during extreme weather conditions, a result that is in line with the observations of contemporaries. Wybrands (1914), for example noted that in 1911 the effects of the summer heat were most strongly felt in the province of Zeeland.

Most of the few studies describing long-term changes in the temperature mortality relation have focused on the reduced effects of cold and have described these changes as a consequence of a diminished exposure to cold, because of the improvement in housing conditions and improvements in clothing, footwear, working conditions and transport. The elderly were more likely than other groups to live in homes with insufficient heating and may have been reluctant to turn on heating because of worries of payment of bills. Their economic and housing situation has considerable improved. In particular indoor cold exposure (a result of bad housing conditions, inadequate heating and large temperature differences between rooms) and exposure to cold during brief excursions outdoors have been reduced. Cold-related mortality was partly due to increased air pollution with SO_2 in a time when home heating was mainly with coal. The transition to other heating methods has played a role in the decrease in winter excess mortality. Also, delayed effects of winter cold such as depletion of fuel, degradation of food quality lost their importance because of rising standards of living (Kunst et al., 1991).

Studies that observed decreases in the effect of heat on mortality are rather rare and do not specifically refer to the age group that underwent the strongest change, infants (Carson et al., 2006; Hare et al., 1981). Given the prominent role that infant deaths played in the temperature-mortality relationship it is clear that the causes of the changes over time in the effect of heat, the reasons behind the higher vulnerability of unskilled workers and the regional differences in vulnerability primarily have to be found 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 mainly caused by high rates of gastro-intestinal diseases (Rombouts, 1902, 98, 102). In normal years, mortality due to 'diarrhoea and enteritis' and other acute gastro-intestinal diseases was already characterized by a strong summer peak and this was even more the case when temperatures were extremely high for a longer period.[16] The high mortality due to gastro-intestinal 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 was the main reason 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 food stuff such as milk and bread porridge deteriorated at high temperatures, the quality of the water, used to dilute the milk, or to prepare other foodstuff, was during periods of heat and drought extremely bad as well, 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 for infants, improvements in the quality of feeding bottles, in the quality of drinking water and milk etc. have contributed to this change. Changes in infant feeding patterns were not the only factor at work however.

16 In Zeeland for example in 1910 and 1912 these acute gastro-intestinal diseases caused a doubling of the total number of deaths in July and August; in the exceptional hot summer of 1911 these causes of death doubled the total death toll in July, increased the number of deaths in August by a factor 4, and the number in September by a factor 2.5.

Housing conditions played a role as well. Whereas high housing density and sanitation problems until at least the beginning of the twentieth century facilitated the spread of disease during hot weather, this changed to the better from the first decades of the twentieth century. Change in food production, food storage and food distribution were another important factor. The growth of refrigerated food storage has reduced the 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 breast-fed children via their mothers. More and better bedding and clothing used for infants and the heating of homes might be a factor: the opening or closing of bedroom doors and windows, the clothing worn by the infant and the layers of the bed clothing, being tucked in firmly, bed sharing all could affect the capacity of infants to maintain a stable body temperature (Watson, Potter, Gallucci, & Lumley, 1998). Crowding of people indoors (which increases temperatures and humidity) and cooking in living spaces (which has the same effect) has been decreased. Also, insects, responsible for the transmission of gastro-intestinal 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).

Most of the above-mentioned factors played a role also 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 and the region over time. Poor unskilled industrial and farm workers and their family members were extremely vulnerable to extreme weather circumstances as a consequence of bad and crowded housing, insufficient clothing and footwear, extreme working conditions, malnutrition of infants – due to low frequencies of breast-feeding and inadequate artificial feeding –, etc etc. Infant mortality in Zeeland was for a long time by far the highest in the Netherlands, a combined effect of low incidence of breast-feeding 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 the 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, in particular during summer periods. It was a mixture of factors that improved the situation of the lowest social class and the worse-faring province: increased frequency and duration of breast-feeding, increased use of proprietary artificial food for infants, better quality of drinking water and milk, improved housing conditions and sanitation, change in food storage, better clothing for infants, heating of homes, decreased dwelling density, changes in water management etc. Cultural, technological and economic changes were the driving forces between this decreased vulnerability to extreme weather conditions.

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Table 1. Expectation of life at birth, by sex, period and province

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

Table 2. Characteristics of the mortality and temperature data in the Dutch provinces of Drenthe, Gelderland and Zeeland by period, 1855-1950

	Drenthe[a]				Gelderland[b]				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]	
Number of observations (days)	9131	9131	9131	7670	9131	9131	9131	7670	9131	9131	9131	7670	105071
Number of deaths	62065	71599	71396	58431	191510	197915	185812	159424	129416	100259	78826	54919	1361572
Mean number of deaths per day	6.8	7.8	7.9	7.6	21.0	21.7	20.5	20.8	14.2	11.0	8.6	7.2	38.8
Percentage of deaths by sex													
Females	48.1	46.1	44.9	42.9	48.0	46.9	46.4	44.6	48.5	48.0	48.0	47.1	46.8
Males	51.9	53.7	50.8	51.3	52.0	52.2	49.8	50.2	51.5	51.8	50.3	49.3	51.2
Percentage of deaths by age													
Stillbirths	7.9	8.9	8.8	7.5	8.0	8.0	7.8	7.3	7.8	7.9	6.9	6.1	7.8
Age < 1 year	17.6	18.7	17.6	8.8	19.8	21.9	16.2	8.0	33.6	30.6	18.6	6.0	19.0
Age 1-4 years	14.9	12.9	9.4	4.1	13.2	10.8	7.5	3.2	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	7.2	6.1	5.4	3.6	6.6
Age 20-49 years	20.4	17.3	16.0	15.9	17.3	14.5	14.6	14.5	15.2	12.1	13.3	12.5	15.2
Age 50-74 years	22.2	2.4	25.2	32.7	22.5	25.2	28.8	35.4	17.6	21.5	27.1	37.7	25.1
Age 75 years or older	8.0	10.2	15.9	25.8	9.9	12.7	19.2	26.9	6.1	12.6	22.9	31.9	16.0
Percentage of deaths by social class													
Unskilled workers	29.5	34.2	32.1	17.1	30.9	28.8	20.5	11.0	47.1	37.3	25.4	12.6	27.4
Semi-skilled workers	3.9	3.4	3.1	3.5	6.6	6.8	5.6	4.9	8.0	7.2	6.1	4.7	5.7
Skilled workers	7.8	7.4	6.3	5.5	12.7	14.4	10.3	7.9	9.5	10.0	7.7	6.0	9.8
Farmers	18.1	17.8	16.8	13.5	14.1	15.5	15.8	11.7	8.6	7.9	7.6	6.4	13.1
Middle class (without farmers)	8.9	8.8	7.3	6.4	8.3	9.4	7.9	7.8	13.3	13.7	9.4	7.3	9.2
Elite	0.8	0.7	0.7	1.2	1.4	1.4	1.3	1.8	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	12.2	22.7	42.7	61.7	33.5
Mean temperatures (° C)													
Daily (24 hour) mean	8.7	8.5	8.7	9.1	9.6	9.3	9.1	9.4	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	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	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	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	0.6	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	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	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	46	59	59	55	53
Hellmann (or cold) value	88	104	82	104	82	88	71	97	36	47	36	50	73
Number of heat waves/cold spells[f]													
Heat waves	1	4	7	6	3	3	8	13	1	0	1	2	31
Cold spells	6	9	6	10	10	9	4	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)

Table 3. 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

	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

	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		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

Table 4a. 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 = overdisperion parameter, r^2 = ordinary correlation coefficient between observed and estimated dependent variable, overdisperion 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)

Table 4b. 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	7641	7641	7641	7641	7641	7641	7641	7641	7641	7641	7641	7641	7641	7641
Mean no. of deaths (± SD)	20.4(±6.9)	9.5(±4.0)	10.4(±4.2)	3.7(±2.8)	1.8(±1.7)	1.3(±1.3)	3.0(±1.9)	5.6(±3.0)	3.3(±2.6)	4.9(±3.1)	1.2(±1.2)	2.3(±1.7)	3.0(±1.9)	2.0(±1.5)
Heat														
day 0	0.0297**	0.0247**	0.0351**	0.0437**	0.0317**	0.0410**	0.0348**	0.0194**	0.0300**	0.0378**	0.0124	0.0319**	0.0272**	0.0307**
lag-days 1-2	0.0136**	0.0142**	0.0121*	0.0190*	0.0084	-0.0021	0.0030	0.0184**	0.0180	0.0075	0.0223	0.0122	0.0043	0.0092
lag days 3-6	0.0010	-0.0024	0.0056	0.0036	0.0129	0.0172	0.0144	-0.0148*	-0.0026	0.0068	-0.0019	0.0002	-0.0070	0.0126
lag days 7-14	0.0187**	0.0179**	0.0207**	0.0531**	0.0181	-0.0092	0.0205**	0.0076	0.0050	0.0174*	0.0395**	0.0149	0.0132	0.0312**
lag days 15-30	0.0315**	0.0355**	0.0299**	0.1029**	0.0610**	0.0068	0.0142	0.0022	-0.0165	0.0600**	0.0422**	0.0361**	0.0268**	0.0349**
Cold														
day 0	-0.0100**	-0.0097**	-0.0107**	-0.0203**	-0.0236**	-0.0093	-0.0022	-0.0055*	-0.0077*	-0.0174**	-0.0093	-0.0139**	-0.0107**	-0.0139**
lag-days 1-2	0.0114**	0.0088**	0.0148**	0.0215**	0.0236	0.0079	0.0019	0.0086**	0.0104*	0.0189**	0.0067	0.0159**	0.0093	0.0121*
lag days 3-6	0.0116**	0.0142**	0.0082**	0.0092*	-0.0001	0.0075	0.0081*	0.0137**	0.0225**	0.0047	0.0075	0.0028	0.0100**	0.0093*
lag days 7-14	0.0052**	0.0048*	0.0059**	-0.0070	-0.0016	-0.0063	0.0014	0.0120**	0.0192**	0.0004	-0.0013	-0.0043	0.0055	0.0016
lag days 15-30	-0.0020	0.0016	-0.0062**	-0.0373**	-0.0110*	0.0000	0.0054	0.0085**	0.0112**	-0.0164**	-0.0100*	-0.0187**	-0.0032	-0.0157**
Seasonal trend	0.0359**	0.0333**	0.0433**	0.1291**	0.1173**	0.0452**	0.0257**	-0.0050	-0.0142**	0.0968**	0.0697**	0.0970**	0.0426**	0.0621**
α	0.0225**	0.0259**	0.0277**	0.2186**	0.2752**	0.1729**	0.0514**	0.0435**	0.1503**	0.1674**	0.0875**	0.0924**	0.0499**	0.0538**
r^2	0.5910	0.5076	0.4819	0.3167	0.2608	0.1351	0.2415	0.4537	0.4563	0.3323	0.1712	0.2451	0.2951	0.2044
r^2_α	0.6278	0.6314	0.5733	0.2401	0.2212	0.1015	0.3327	0.5650	0.4587	0.2474	0.2441	0.2876	0.4264	0.3203

[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 = overdisperion parameter, r^2 = ordinary correlation coefficient between observed and estimated dependent variable, overdisperion 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)

Table 4c. 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 = overdisperion parameter, r^2 = ordinary correlation coefficient between observed and estimated dependent variable, overdisperion 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)

Table 5a. 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 = overdisperion parameter, r² = ordinary correlation coefficient between observed and estimated dependent variable, overdisperion 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)

Table 5b. 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 = overdisperion parameter, r^2 = ordinary correlation coefficient between observed and estimated dependent variable, overdisperion 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)

Table 5c. 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 = overdisperion parameter, r^2 = ordinary correlation coefficient between observed and estimated dependent variable, overdisperion 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)

Table 6a. 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]				Gelderland [b]				Zeeland[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	5291	3335	5306	5306	5291	3305
Mean no. of deaths (± SD)	1.2(±1.2)	1.5(±1.3)	1.4(±1.3)	0.6(±0.9)	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	0.0566**	0.0485**	0.0350*	-0.0068	0.0517**	0.0336**	0.0372**	0.0298*	0.0298**	0.0333**	0.0197	0.0103
lag-days 1-2	0.0509**	-0.0054	0.0460**	0.0066	0.0189*	0.0206**	0.0433**	0.0063	0.0027	-0.0072	0.0077	0.0188
lag days 3-6	0.0243	0.0362*	0.0178	0.0135	-0.0026	0.0160	0.0051	0.0009	0.0150	0.0321**	0.0299*	-0.0557
lag days 7-14	0.1066**	0.0867**	0.0417*	-0.0006	0.0642**	0.0819**	0.0565**	-0.0098	0.1046**	0.1106**	0.1021**	-0.0475
lag days 15-30	0.1366**	0.1167**	0.1351**	0.0991**	0.1019**	0.1137**	0.1755**	0.0868**	0.2050**	0.1873**	0.1990**	0.0504
Cold												
day 0	0.0017	-0.0135*	-0.0177**	-0.0299*	-0.0175**	-0.0202**	-0.0235**	-0.0139*	-0.0054	-0.0079	-0.0346**	-0.0126
lag-days 1-2	0.0149	0.0284**	0.0261**	0.0212	0.0221**	0.0235**	0.0188**	0.0082	0.0241**	0.0165*	0.0199*	0.0229
lag days 3-6	0.0122	0.0033	0.0000	0.0177	0.0097*	0.0125**	0.0125**	0.0296**	0.0190**	0.0119*	0.0211**	0.0170
lag days 7-14	-0.0136*	-0.0094	-0.0068	0.0073	-0.0052	0.0009	-0.0081	0.0025	-0.0098*	-0.0023	-0.0247**	0.0265
lag days 15-30	-0.0189**	-0.0186**	-0.0419**	0.0379**	-0.0333**	-0.0055	-0.0524**	0.0195**	-0.0485**	-0.0329**	-0.0633**	-0.0040
Seasonal trend	0.1843**	0.1195**	0.2896**	-0.1236*	0.1061**	-0.0162*	0.1571**	-0.0014	0.0644**	0.0903**	0.4794**	0.0135
α	0.0729**	0.0383**	0.1297**	0.4364**	0.0521**	0.0383**	0.1397**	0.0995**	0.0681**	0.1019**	0.1316**	0.2501**
R^2	0.2410	0.1850	0.2423	0.1743	0.3897	0.3659	0.4190	0.3211	0.6085	0.5169	0.5733	0.2189
R^2_α	0.4350	0.4026	0.2812	0.1628	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 ($p<0.01$)
α = overdisperion parameter, r^2 = ordinary correlation coefficient between observed and estimated dependent variable, overdisperion 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)

Table 6b. 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]

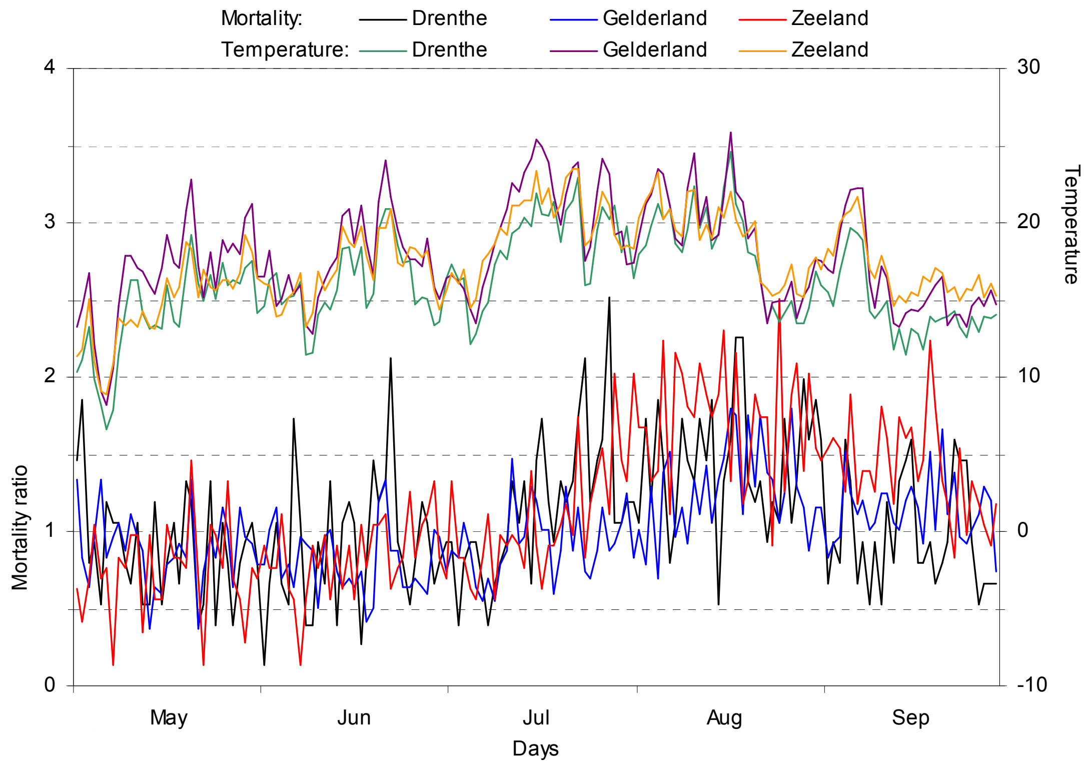
	Drenthe[b]				Gelderland [b]				Zeeland[b]			
	1855-79	1880-04	1905-29[a]	1930-50[a]	1855-79	1880-04	1905-29[a]	1930-50[a]	1855-79	1880-04	1905-29[a]	1930-50[a]
Number of observations	5306	5306	5232	3335	5306	5306	5291	3335	5306	5306	5291	3305
Mean no. of deaths (± SD)	1.2(±1.2)	1.5(±1.3)	1.4(±1.3)	0.6(±0.9)	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	0.0566**	0.0485**	0.0350*	-0.0068	0.0225*	0.0228*	0.0497**	0.0234**	0.0492*	0.0089	0.0513**	0.0403**
lag-days 1-2	0.0509**	-0.0054	0.0460**	0.0066	0.0109	0.0058	0.0140	0.0161	-0.0009	0.0220	-0.0084	0.0002
lag days 3-6	0.0243	0.0362*	0.0178	0.0135	-0.0152	0.0033	0.0036	0.0128	-0.0317	-0.0363	-0.0065	-0.0073
lag days 7-14	0.1066**	0.0867**	0.0417*	-0.0006	0.0194	-0.0098	0.0080	-0.0118	-0.0101	0.0186	0.0117	0.0033
lag days 15-30	0.1366**	0.1167**	0.1351**	0.0991**	0.0019	0.0315*	0.0023	0.0027	0.1216**	0.0164	0.0161	-0.0023
Cold												
day 0	0.0017	-0.0135*	-0.0177**	-0.0299*	-0.0060	-0.0131**	-0.0104**	-0.0079*	-0.0040	-0.0125	-0.0055	-0.0122
lag-days 1-2	0.0149	0.0284**	0.0261**	0.0212	0.0139*	0.0204**	0.0129**	0.0011	0.0162	0.0334**	0.0087	0.0147
lag days 3-6	0.0122	0.0033	0.0000	0.0177	0.0221**	0.0157**	0.0228**	0.0155**	0.0286**	0.0082	0.0203**	0.0076
lag days 7-14	-0.0136*	-0.0094	-0.0068	0.0073	0.0211**	0.0194**	0.0196**	0.0086*	0.0347**	0.0199**	0.0340**	0.0132*
lag days 15-30	-0.0189**	-0.0186**	-0.0419**	0.0379**	-0.0174**	0.0137**	0.0148**	0.0063	-0.0113	0.0181**	0.0077	0.0077
Seasonal trend	0.1843**	0.1195**	0.2896**	-0.1236*	0.0489**	-0.0043	-0.0077	0.0571**	-0.1129**	-0.1631**	-0.0294**	0.1230**
α	0.0729**	0.0383**	0.1297**	0.4364**	0.0389**	0.0598**	0.0443**	0.0306**	0.0146	0.0516**	0.0483**	0.0408**
R^2	0.2410	0.1850	0.2423	0.1743	0.4543	0.4852	0.5446	0.5555	0.3340	0.3660	0.4196	0.4273
R^2_α	0.4350	0.4026	0.2812	0.1628	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 = overdisperion parameter, r^2 = ordinary correlation coefficient between observed and estimated dependent variable, overdisperion 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)

Figure 1. Map of the Netherlands by province, around 1900

Figure 2. Daily mortality ratio and average 24-hour temperature (°C) in the Dutch provinces Drenthe, Gelderland and Zeeland in the summers of 1868, 1884, 1911 and 1947

(a) Summer 1868



(b) Summer 1884

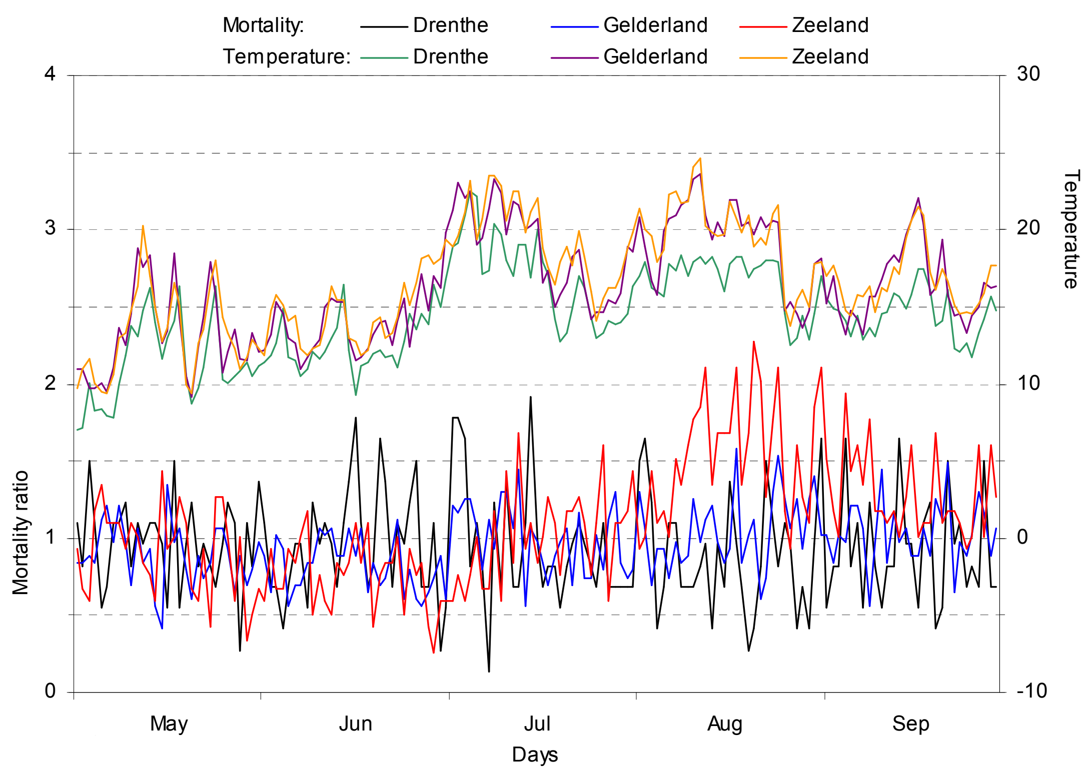
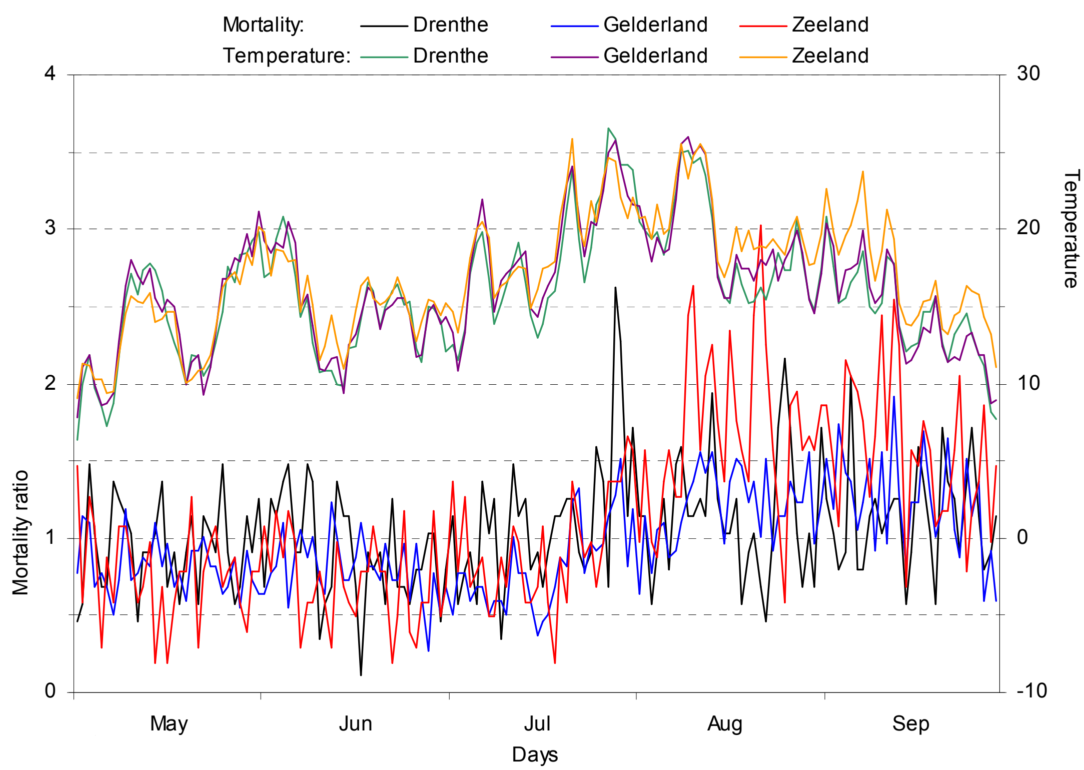


Figure 2 (cont.). Daily mortality ratio and average 24-hour temperature (°C) in the Dutch provinces Drenthe, Gelderland and Zeeland in the summers of 1868, 1884, 1911 and 1947

(c) Summer 1911



(d) Summer 1947

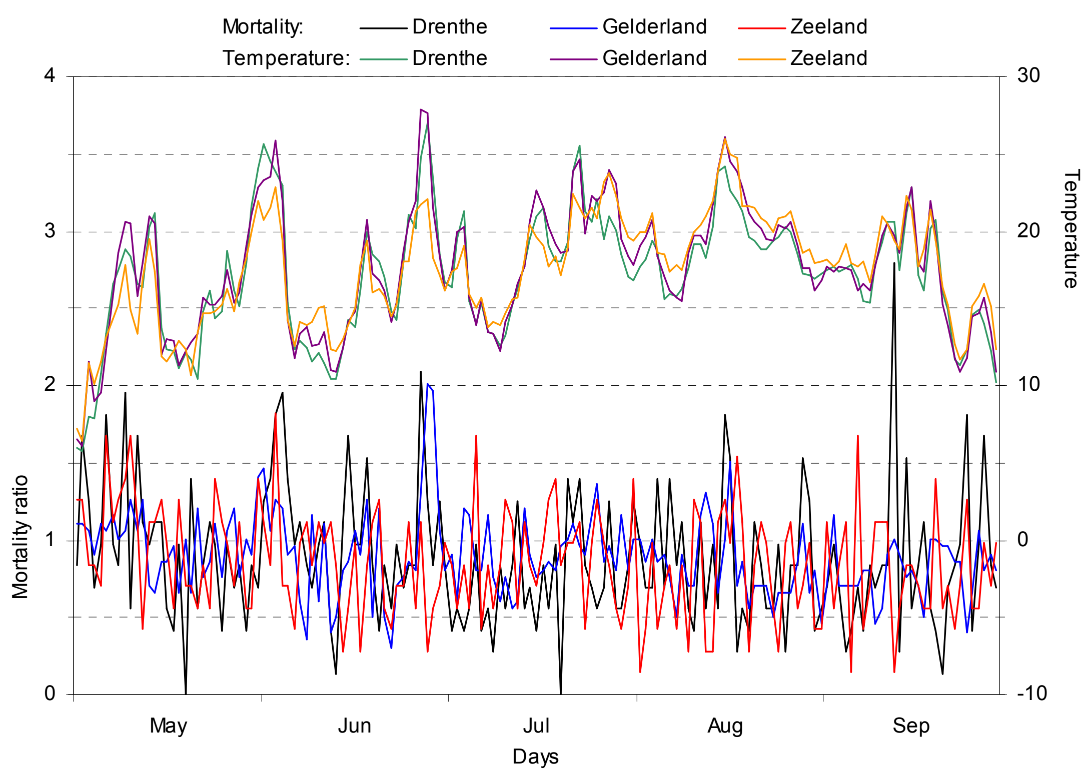
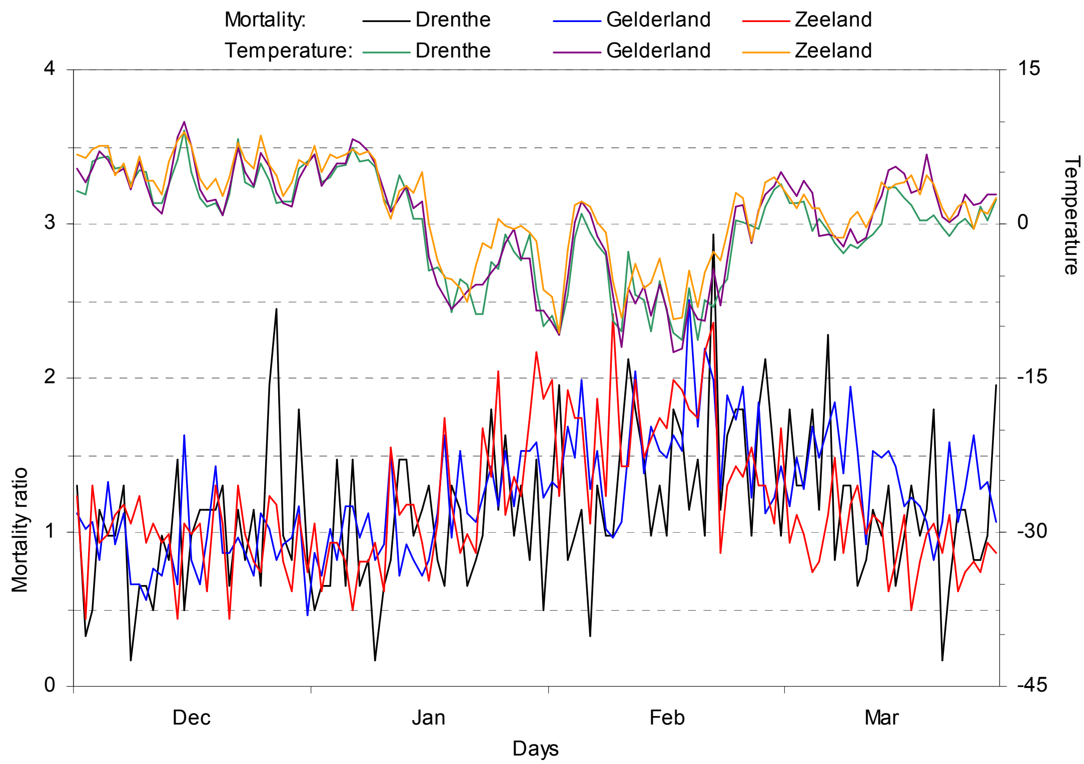


Figure 3. Daily mortality ratio and average 24-hour temperature (°C) in the Dutch provinces Drenthe, Gelderland and Zeeland in the winters of 1854-55, 1890-91, 1928-29 and 1946-47

(a) Winter 1854-55



(b) Winter 1890-91

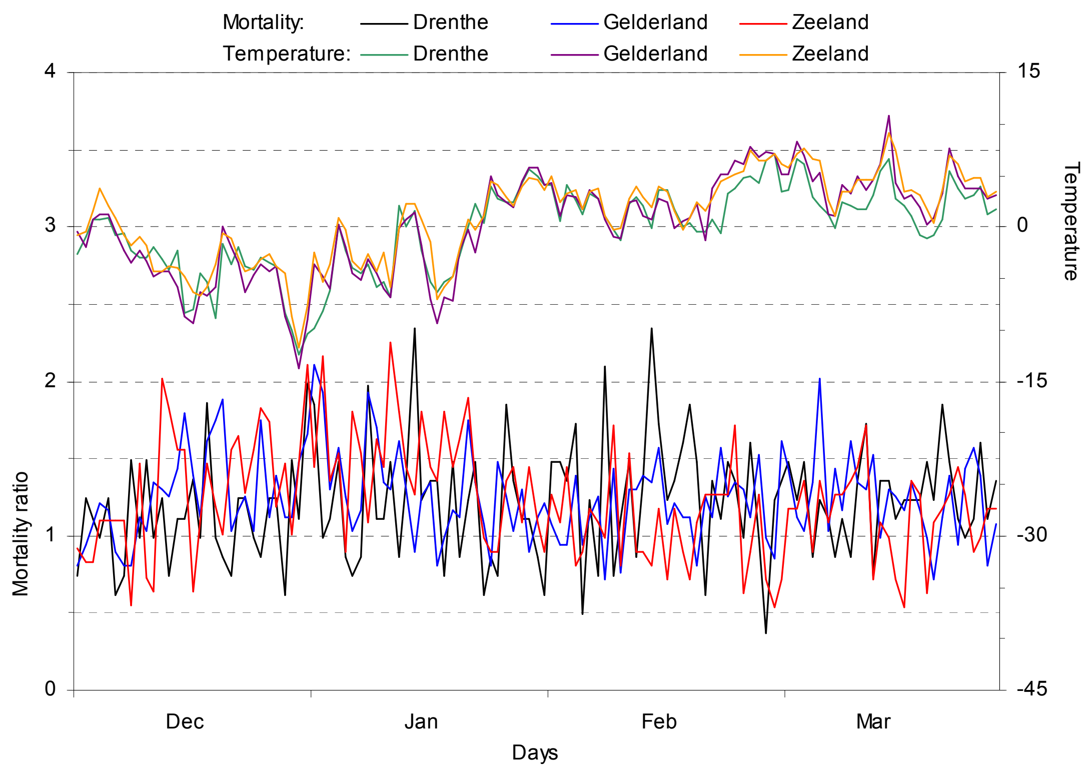
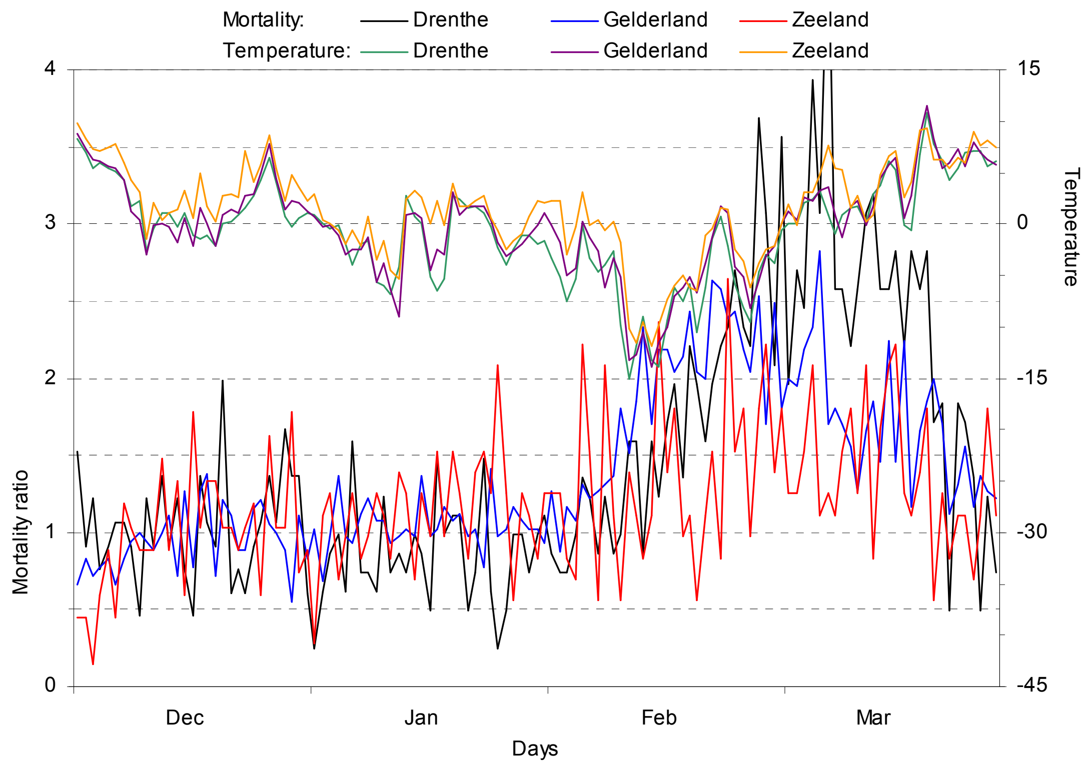


Figure 3 (cont.). Daily mortality ratio and average 24-hour temperature (°C) in the Dutch provinces Drenthe, Gelderland and Zeeland in the winters of 1854-55, 1890-91, 1928-29 and 1946-47

(c) Winter 1928-29



(d) Winter 1946-47