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Mortality related to cold and heat. What do we learn from dairy cattle?

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ABSTRACT

Extreme temperatures are associated with increased mortality among humans. Because similar epidemiologic studies in animals may add to the existing evidence, we investigated the association between ambient temperature and the risk of mortality among dairy cattle. We used data on 87,108 dairy cow deaths in Belgium from 2006 to 2009, and we combined a case-crossover design with distributed lag non-linear models. Province-specific results were combined in a multivariate meta-analysis. Relative to the estimated minimum mortality temperature of 15.4 °C (75th percentile), the pooled cumulative relative risks over lag 0–25 days were 1.26 (95% CI: 1.11, 1.42) for extreme cold (1st percentile, −3.5 °C), 1.35 (95% CI: 1.19, 1.54) for moderate cold (5th percentile, −0.3 °C), 1.09 (95% CI: 1.02, 1.17) for moderate heat (95th percentile, 19.7 °C), and 1.26 (95% CI: 1.08; 1.48) for extreme heat (99th percentile, 22.6 °C). The temporal pattern of the temperature-mortality association was similar to that observed in humans, i.e. acute effects of heat and delayed and prolonged effects of cold. Seasonal analyses suggested that most of the temperature-related mortality, including cold effects, occurred in the warm season. Our study reinforces the evidence on the plausibility of causal effects in humans.

1. Introduction

It is well recognized that in developed countries, the major health consequences of climate change will be due to extreme weather events (IPCC, 2012). Daily variations in ambient temperature are associated with daily variations in human morbidity and mortality, with increased health risks at both ends of the temperature distribution (Gasparrini et al., 2015b; Guo et al., 2014).

Also farm animals such as cattle are known to suffer from temperature extremes. Studies have mainly focused on heat-related reductions in feed intake, milk yield, growth rate and reproductive performance (Kadzere et al., 2002). Despite the major economic burden of livestock mortality, the effect of temperature on death rates has received less attention (Mader et al., 2001; Stull et al., 2008; Vitali et al., 2009; Crescio et al., 2010; Morignat et al., 2014, 2015). On-farm death of dairy cows has increased in recent years and there is large uncertainty about the exact causes of death (Thomsen and Houe, 2006). As lactating dairy cows create a large quantity of metabolic heat, they tend to be much more tolerant for low than for high temperatures (Kadzere et al., 2002). Consequently, effects of cold have not been studied much. Nevertheless, few studies reported cold-related decreases in milk yield (Brouček et al., 1991) and increases in mortality (Morignat et al., 2015; Stull et al., 2008).

The investigation of dairy cow mortality in relation to environmental risk factors might add to the epidemiological evidence on human health risks. Despite the recognition that animals could be useful sentinels for human (van der Schalie et al., 1999), the full potential of linking animal and human health information has not been realized (Rabinowitz and Conti, 2013). Reasons appear to include the professional segregation of human and animal health communities, the separation of human and animal surveillance data, and evidence gaps in the linkages between human and animal responses to environmental health hazards (Rabinowitz and Conti, 2013). Animal populations have the advantage that

Abbreviations: CI, confidence interval; Df, degrees of freedom; DLNM, distributed lag non-linear model; NO_2, nitrogen dioxide; O_3, ozone; MMT, minimum mortality temperature; PM_{10}, particulate matter with diameter less than 10 μm; RR, relative risk; SD, standard deviation

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they are less subject to exposure misclassification than human populations (Reif, 2011). Also confounding factors such as occupational exposures, lifestyle factors, housing construction, and the use of air conditioning, are absent or limited in animal species such as dairy cows.

In this study, we investigated whether the short-term association between temperature and mortality in humans can be corroborated in an animal population, to further elaborate on the causality of this association. We applied a multivariate meta-analysis on province-specific associations in Belgium, allowing for non-linear as well as delayed temperature effects through the use of distributed lag non-linear models (DLNM) (Gasparrini et al., 2010). A DLNM has the advantage of providing cumulative effects of temperature by flexibly estimating contributions at different lag times, thus accounting for delayed effects and short-term mortality displacement (harvesting).

2. Materials and methods

2.1. Data

Data on cattle mortality were extracted from Sanitrace, a national-level computerized database for the registration and traceability of farm animals (Federal Agency for the Safety of the Food Chain, 2012). Our study population consisted of all adult dairy cows (≥ 2 years) that died (different from culling in slaughterhouse) in Belgium during the period 2006–2009.

Province-specific data on daily mean air temperature and average relative humidity were provided by the Belgian Royal Meteorological Institute. Belgium has 10 provinces with an average size (range) of 3035 (1093–4443) km^2 (Fig. 1). We used data from 9 meteorological measuring stations as mortality data from Flemish and Walloon Brabant (and the Brussels Region) were aggregated because of low daily death counts.

As ambient air pollution levels might confound the association between temperature and mortality (Analitis et al., 2014; Cox et al., In press), we obtained data on ozone (O_3, 8-h maximum values), particulate matter with diameter less than 10 µm (PM_{10}, daily averages), and nitrogen dioxide (NO_2, daily averages) from the Belgian Interregional Environment Agency. In Belgium, air pollution is measured by a dense network of automatic monitoring sites (average distance between the nearest measuring stations is 25 km), collecting real-time data on a half-hourly basis. Daily air pollution concentrations at the level of the municipality are obtained by a spatial-temporal (Kriging) interpolation model that combines data from monitoring stations with land cover data obtained from satellite images (Janssen et al., 2008). Daily province-specific average air pollution concentrations were calculated by weighing the municipality-specific concentrations by the number of animals (herd size at the moment of data extraction) per municipality.

2.2. Statistical analysis

The association between ambient temperature and dairy cattle mortality was investigated by using a case-crossover design (Nawrot et al., 2011). Each subject serves as its own control so that known and unknown time-invariant confounders are inherently adjusted for by study design (Maclure, 1991). We used the bidirectional time-stratified design to avoid selection bias (Levy et al., 2001). Control days were taken from the same calendar month and year as the case day (i.e. day of death), both before and after the case, thus controlling for long-term trends and season by design. Cases and controls were additionally matched by day of the week to control for any weekly patterns in deaths.

In this study, we used conditional quasi-Poisson models that allow for overdispersion in daily deaths. When subjects have a common (province-level) exposure, the case-crossover using conditional logistic regression is a special case of time-series analysis (Lu and Zeger, 2007). Data can be aggregated into daily counts per province, and a Poisson model with stratum indicators gives identical estimates to those from conditional logistic regression. Although conditional Poisson models are computationally less intensive than conditional logistic models and they can allow for overdispersion or auto-correlation in the original counts, they are little used (Armstrong et al., 2014). We controlled for public holidays as an indicator variable and we adjusted for the moving average of humidity on the current day and the previous day (lag 0–1) using a natural cubic spline with 3 degrees of freedom (df).

In a first stage, we estimated province-specific associations between temperature and mortality by using DLNMs, which allow

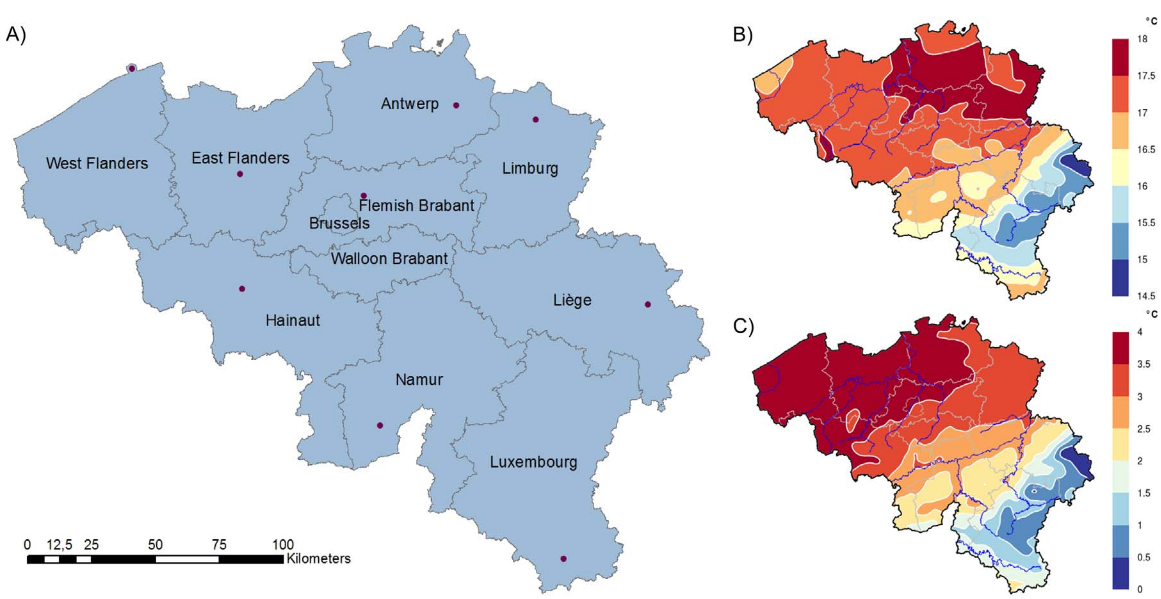

Fig. 1. The location of provinces and measuring stations from which temperature data were used in this study (A), and mean temperatures gradients (1981–2010) for summer (B) and winter (C), Belgium. Source (B and C): Belgian Royal Meteorological Institute ⟨http://www.meteo.be/meteo/view/fr/16788784-Atlas+Climatique.html⟩.