BMJ Open

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Journal:	*BMJ Open*
Manuscript ID	bmjopen-2017-018068
Article Type:	Research
Date Submitted by the Author:	05-Jun-2017
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Primary Subject Heading:	Epidemiology
Secondary Subject Heading:	Global health, Public health
Keywords:	Heat, Year of life lost, Non-communicable disease, Sub-Saharan Africa, Time-series

Excess burden of non-communicable disease years of life lost from heat in rural Burkina Faso: a time-series analysis of the years 2000-2010

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Abstract

Objectives

Investigate the association of heat exposure on years of life lost (YLL) from non-communicable diseases (NCD) in Nouna, Burkina Faso between 2000-2010.

Design

Daily time-series regression analysis using distributed lag non-linear models, assuming a quasi-Poisson distribution of YLL.

Setting

Nouna Health and Demographic Surveillance System, Kossi Province, Rural Burkina Faso.

Participants

18,367 NCD-YLL corresponding to 790 NCD deaths recorded in the Nouna HDSS register over 11 years.

Main outcome measure

Excess mean daily NCD-YLL were generated from the relative risk of maximum daily temperature on NCD-YLL, including effects delayed up to 14 days.

Results

Daily average NCD-YLL were 4.6, 2.4 and 2.1 person-years for all-ages, males and females, respectively. Moderate 4-day cumulative rise in maximum temperature from 36.4°C (50th percentile) to 41.4°C (90th percentile) resulted in 4.44 (95% CI 0.24 to 12.28) excess daily NCD-YLL for all-ages, rising to 7.39 (0.32 to 24.62) at extreme temperature (42.8°C; 99th percentile). The strongest health effects manifested on the day of heat exposure (lag 0), where 0.81 (0.13 to 1.59) excess mean NCD-YLL occurred daily at 41.7°C compared to 36.4°C, diminishing in statistical significance after 4 days. At lag 0, daily excess mean NCD-YLL were higher for males 0.58 (0.11 to 1.15) compared to females 0.15 (-0.25 to 9.63) at 41.7°C versus 36.4°C.

Conclusion

Premature death from NCD was elevated significantly with moderate and extreme heat exposure. These findings have important implications for developing adaptation and mitigation strategies to reduce ambient heat exposure and preventive measures for limiting NCD in Africa.

Key words: temperature, heat, years of life lost, non-communicable disease, Africa, time-series.

Strengths and limitations of this study

- This study investigated the relationship between two defining public health issues affecting Sub-Saharan Africa; increasing ambient heat from climate change and the rising prevalence of non-communicable disease
- Eleven years of high-quality health and demographic data from rural Africa was exploited for analysis
- Only premature death was quantified as the outcome because long-term morbidity data were unavailable
- Temperature data from a weather station located 53 km from the study location was used as a proxy for individual level temperature exposure.

Introduction

As the global average temperature rises, epidemiological evidence on the temperature-health association in neglected African populations is needed to develop appropriate interventions. Surface temperature over West Africa and the Sahel increased by 0.5-0.8°C between 1970 and 2010, and at a faster pace in the most recent 20 years [1]. Analysis of longitudinal data from 12 Health and Demographic Surveillance Sites (HDSS), which includes the Nouna HDSS in Burkina Faso, forecasts that the mean temperature in Africa will exceed the 1900-2000 decadal average by 2100 under all climate change scenarios [2]. In a study applying six climate model-future scenarios across six HDSS sites, the most conservative combination, rapid economic growth and balanced energy sources resulted in a 0.5-1°C temperature increase by 2100, whereas most combinations projected a 2-3°C temperature rise in the same period [2]. Prolonged exposure to high ambient temperature in the subsistence farming community of Nouna, and low adaptive capacity makes this community particularly vulnerable to the effects of temperature increase.

Non-communicable disease (NCD) cause substantial economic drain to society by adversely affecting four pillars of economic growth; labour supply, productivity, investments and education. Projections from 2006 indicated that if no action was taken to reduce the risk of NCD in 23 low-and-middle income countries, US$83 billion would be lost over the subsequent decade to the impact of heart disease, stroke and diabetes [3]. As life expectancy increases in Burkina Faso, people will have more time to develop chronic and degenerative disorders; NCD will therefore contribute increasingly to population mortality. In 2014, NCD accounted for 32% of all deaths in Burkina Faso. The main contributors were cardiovascular disease, cancer, chronic respiratory disease and diabetes [4]. In 2011, Friel *et al.* presented a review exposing the link between climate change and a wide range of NCD, and argued that more frequent and intense heat extremes could exacerbate cardiovascular and respiratory health outcomes [5].

Previous studies have explored the impact of extreme events such as heatwaves or cold waves [6,7] on health, which are anticipated to increase in frequency and magnitude with climate change [8]. A recent multicity study, however, found that milder non-optimal temperature rather than extreme temperature was responsible for most of the temperature-related mortality burden (defined as below the 2.5th and above the 97.5th percentile) [9]. Unfortunately, no African studies were included by Gasparrini et al. [9]. Heat (and cold) waves are defined by magnitude and duration; for example, two or more consecutive days exceeding the 98-99th (or 1-2nd) percentile of the temperature range. Excess risks are a comparison of heatwave periods with non-heatwaves periods in previous years. Our study investigates the health risks of moderate to extreme heat, where extreme temperature is defined as below the 5th and above the 95th percentiles of maximum temperature.

Epidemiological studies on the temperature-health association in African populations have primarily measured daily deaths as the outcome [10,11]. Rather than the number of deaths, we used years of life lost (YLL), a global burden of disease (GBD) outcome metric for ascertaining premature death. YLL is an aggregate of life expectancy and death counts that gives the absolute value of years of life lost from a certain exposure, rather than a relative risk. In the only previous study set in Africa investigating the temperature-YLL association, Egondi et al. found no heat effects on *all-cause* YLL in the East African highlands of Nairobi, Kenya. A reduction in temperature (21°C compared with 26°C), however, resulted in 27.4 excess all-cause YLL per day (95% CI 2.7 to 52.0) [12]. Africa faces the dual challenge of coping with rising temperatures from climate change and increasing prevalence of NCD. The paucity of population-based studies set in African focused on the impact of temperature on NCD health outcomes suggests further studies are required. Our study addresses this research gap by investigating the impact of 11 years of heat exposure on YLL from NCD in the Nouna HDSS.

Methods

Data collection

Health outcome data were obtained from the HDSS, Centre de Recherche en Santé de Nouna, Burkina Faso [13]. All registered deaths between 1 January 2000 to 31 December 2010 were included. Vital statistics for each resident included a unique identifying number (ID), date of birth, date of immigration into the HDSS, date of death, date of emigration from the HDSS and gender. Raw mortality data comprised a unique ID number for each death event, date of birth, date of death, sex, cause of death coded as an International Classification of Disease (ICD10) code, and an accompanying cause of death in French. Cause of death was established by verbal autopsy [14]. Age of death was calculated as the difference between the date of death and birth. We applied the GBD cause-specific categories and ICD10 codes to define NCD as an aggregate of: malignant neoplasms (C00-C97), other neoplasms (D00-D48), diabetes mellitus (E10-E14), endocrine disorders (D55-D64; minus-D64.9, D65-D89, E03-E07, E15-16, E20-E34, E65-E88), neuropsychiatric conditions (F01-F99, G06-G98), sense organ diseases (H00-H61, H68-H93), cardiovascular diseases (I00-I99), respiratory diseases (J30-J98), digestive diseases (K00-K92), genitourinary diseases (N00-N64, N75-N98), skin diseases (L00-L98), musculoskeletal diseases (M00-M99) and congenital anomalies (Q00-Q99) [15].

Computation of daily years of life lost

Different resolutions of life tables can be used to calculate YLL i.e. global, country-level or local life expectancy depending on the purpose of the study. The GBD approach calculates YLL relative to the life expectancy of Japanese men and women, the highest for any societal group [16]. Weights for age and time preference can additionally be applied to reduce the contribution of death before adulthood [17]. This study used local rather than global life tables, as done in similar studies [18-20] to present realistic potential losses or gains in life years for the Nouna population grounded in real data (rather than modelled data), which is more meaningful for local decision makers. The cause of death and demographic data from the Nouna HDSS were used to build life tables for the Nouna population. The use of global life expectancy would likely produce very large YLL for populations with low life expectancy such as in Burkina Faso. Furthermore, global life expectancy is likely to be more useful when comparing YLL between two countries, which was not the aim of this study.

We used the Nouna HDSS vital statistics from 2000-2010 to produce age-specific death rates. We generated gender-specific life tables to account for varying life expectancies between men and women (details in **Supplementary File**). Mean additional survival time, averaged between 2000-2010 was calculated for each age band to account for the changing population profile over this time. Abridged life tables were created in five-year increments, producing stable life expectancy estimates for a relatively small population (approximately 90,000 inhabitants in 2012 [10]). The 0-1, and 1-5 age groups were, however, separated. Combining these ages would mask the lower remaining life expectancy for the 0-1 age relative to the 1-5 age group, a consequence of high infant mortality. For each NCD death, YLL were calculated by matching age and sex with the relevant life table. Daily YLL were an aggregate of individual YLL on the respective day calculated as:

a) individual YLL at time of death:

$$YLL_{individual\ (i)} = LE_{remaining} - Age_{death} \qquad [1]$$

b) total daily YLL:

$$YLL_{daily} = \sum_{i=1}^{n} YLL_i \qquad [2]$$

where:

i is the ith individual

$LE_{remaining}$ is the conditional life expectancy

Age_{death} is the age at death

n is the number of deaths occurring on a given day.

We stratified NCD-YLL by sex to assess if gender differences existed.

Temperature data

We obtained hourly mean (t-mean), maximum (t-max) and minimum (t-min) temperature data from the National Climatic Data Centre for the Dédougou weather station (12.4° N, 3.4° W) from 1 January 2000 to 31 December 2010 (4071 days). The Dédougou weather station located 53 km away has a comparable temperature profile to Nouna. Hourly data were averaged to give a daily temperature. The raw time-series consisted of 25% missing t-mean, 14% t-max and 17% t-min. We created an imputation algorithm by averaging 15 consecutive days of temperature either side of a missing temperature value to create a 30-day moving average. The Time Indexes and Time Indexed Series (tis) package *v*.1.30 was applied in *R* software to impute missing temperature values.

Statistical modelling

We applied time-series quasi-Poisson regression analysis, using a distributed lag non-linear model (DLNM) to investigate the non-linear association between maximum daily temperature and the relative risk (RR) of NCD-YLL.

A natural cubic spline with eight degrees of freedom per year was applied to control for season and long-term time-trends. A heaping effect was found in the raw data (**Supplementary Table 5 and Supplementary Figure 1-2**), where deaths of an unknown date were assigned to the 9th day of the corresponding month. An indicator variable was added to mark and control for heaping of deaths and day of the week. The DLNM captured the immediate and delayed effects of temperature (lags) on health, known as the lag-response association as single lag days, or as it cumulates over time. The exposure-response curve was modelled with a natural cubic spline with knots placed at the 10th, 50th and 90th percentiles. The lag-response was modelled with a natural cubic spline of two degrees of freedom, resulting in default knot placement equally along a logarithmic scale. The model equation was:

$$E(Y_t) = \beta_o + s(T, timedf) + f(X_{tmax}, lagdf, vardf) + DOW + HP$$
$$E(Y_t) \sim quasi - Poisson \qquad [3]$$

where:

$E(Y_t)$ is the daily YLL

β_o is the y intercept

$s(T, timedf)$ is the smooth function of time with specified df $timedf$

$f(X_{tmax}, lagdf, vardf)$ is the cross-basis function of t-max and the associated lag dimension with *vardf* and *lagdf* degrees of freedom respectively. DOW accounts for day of week and HP for the heaping effect.

From the RR, absolute values of excess mean daily NCD-YLL were calculated as:

$$(Average\ daily\ NCD - YLL \times RR) - Average\ daily\ NCD - YLL \qquad [4]$$

All effect estimates were presented against the median t-max of 36.4°C either as overall 4-day and 14-day cumulative RRs (and corresponding excess mean daily NCD-YLL), or single-day lags extending to 14 days.

Several sensitivity analyses were conducted to test the robustness of altering model choices including; specifying alternative knot positions for exposure-response at the 10^{th}, 75^{th} and 90^{th}, and 10^{th}, 25^{th}, 75^{th} and 90^{th} percentiles, extending degrees of freedom (df) for the lag-response between 2 to 6df, manipulating control for season and time-trend ranging between 5-10df, logarithm transformation of YLL and applying a Gaussian distribution, and extending the lag period to 28 days to assess if temperature exposure triggered NCD deaths on a longer time scale. Quasi-Akaiki information criteria (QAIC) values were calculated to guide model selection. All statistical analyses were conducted using *R* software *v*.3.2.2. Distributed lag non-linear models were fitted using the DLNM package *v*.2.2.3.

Results

The 790 NCD deaths correspond to 18,367 YLL over the study period. Cardiovascular diseases were the largest contributor to NCD-YLL, accounting for 9095 or 50% of all NCD-YLL. Digestive disorders, malignant neoplasms, genitourinary and neuropsychiatric conditions also contributed substantially towards NCD-YLL. Interestingly, endocrine disorders (including diabetes mellitus) formed a very small proportion (1%) of all NCD-YLL **(Table 1)**. **Table 2** shows that maximum mortality peaked at five deaths per day, corresponding to 154 daily NCD-YLL. Daily mean NCD-YLL were 4.6, 2.4 and 2.1 person-years for all-ages, males and females, respectively. Maximum daily temperature was 36.4°C at the 50^{th} percentile, peaking at 43.9°C in the study period.

Figure 1 shows 3D graphs of the RR of NCD-YLL at a range of maximum temperature and lag values, centred at the reference temperature of 36.4°C (all RRs and excess mean daily NCD-YLL in the results are given as a comparison to this reference temperature). All-age (panel A) and male (panel B) plots showed a strong surge in the RR with high temperature close to the time of heat exposure. Males presented no noticeable effect with colder temperature. In contrast, women (panel C) and the all-age group showed more prominent health effects with cooler temperatures, which increased at longer lags.

The main results were the 4- and 14-day cumulative (**Figure 2)** and single-day lagged RR of NCD-YLL **(Figure 3)**, from which daily excess mean NCD-YLL was calculated. Heat effects on NCD-YLL were felt strongly in Nouna above the 50th percentile. Over four cumulative days, exposure to moderate temperature (90th percentile at 41.3°C) was associated with a statistically significant increase of excess mean daily NCD-YLL by 4.44 (0.24 to 12.28) for all-ages, 3.73 (0.33 to 11.39) for males, but remained statistically insignificant for females 0.43 (-1.08 to 4.16). In comparison to the 90th percentile, excess mean daily NCD-YLL increased slightly at 95th percentile (41.7°C) for all ages and males, but not females (**Table 3b**). Extreme heat exposure (99th percentile) over four days increased excess daily mean NCD-YLL for all-ages to 7.39 (0.32 to 24.62) and 8.65 (1.07 to 32.73) for males in contrast to the minimal increase for females; 0.12 (-1.48 to 5.86). Extending the cumulative effect to 14 days also resulted in elevated excess daily mean NCD-YLL, but wider 95% confidence bounds rendered the effect estimates for all three groups statistically insignificance.

Across 14 individual lag days **(Figure 3)**, the largest heat effects were felt immediately (at lag 0); excess daily mean NCD-YLL were 0.81 (0.13 to 1.59) for all-ages, 0.58 (0.11 to 1.15) for males, and 0.15 (-0.25 to 0.63) for females at 41.7°C (**Table 4b**). Heat effects tapered after lag 0, but remained statistically significant to lag 4 at 41.7°C for all-ages and males. For the 95th percentile, a gradual reduction in excess daily mean NCD-YLL (statistically insignificant) was observed up to 8-10 lag days for all-ages, males and females with no subsequent increase.

A reduction in temperature to 30°C **(Figure 3)**, resulted in a slightly protective effect at shorter lags (0-5), but after 14 days the excess daily NCD-YLL were slightly elevated for all subgroup; 0.13 (-0.21 to 0.49) for all-ages; 0.06 (-0.17 to 0.32) for males; and 0.11 (-0.11 to 0.34) for females **(Table 4b)**. Females were the only group to present a statistically significant increase in mean daily NCD-YLL with extreme cold (1st percentile) at lag 13 and 14 **(Supplementary Table 8b)**.

Excess mean daily NCD-YLL were elevated with heat exposure for the 65+ age group, however, the low sample size produced very large confidence bounds (i.e. 0.14 (-0.89 to 86.35) at 38.9°C versus 36.4°C.

Several sensitivity analyses were conducted to validate model selection, including generating QAIC, where lower QAIC indicate better model fit (**Supplementary Tables 9 and 10**). Because increasing the df produces lower QAIC values, we used prior examples to achieve a balance in controlling for season and long-term trend to 8 df per year [9]. Applying 7 df per year, as used in other studies did not greatly affect the risk estimates [20,21]. The natural cubic spline produced lower QAIC in comparison to the more flexible cubic B-spline. Varying knot position and numbers for the exposure-response relationship also did not vary effect estimates. Using 3 df for the lag-response relationship produced the classic reversed J curve expected for heat effects, however, 2 df generated lower QAICs indicating better model fit. There was no evidence of autocorrelation (**Supplementary Figures 6-7**).

Discussion

A central finding of this study was that excess premature deaths from NCD increased with moderate and extreme heat in rural Sub Saharan Africa. The magnitude of health effects worsened with heat intensity. The largest increase in excess premature mortality from NCD occurred rapidly, on the day of heat exposure (lag 0), and diminished in statistical significance after 4 days. The effects of heat on NCD-YLL were greater in males in comparison to females.

In Nairobi, Kenya, increase in temperature over 14 days from 26°C to 30°C resulted in 3.3 (95% CI -19.7 to 26.4) YLL per day, but from *all causes* [12]. Similarly, a change in temperature from the 50th to 75th percentile (36.4 to 38.9°C) in Nouna resulted in 3.01 (-0.84 to 10.82) excess daily *NCD-YLL* over 14 days. Unlike Nouna, the temperature in Nairobi does not typically exceed 40°C. As the only existing African study presenting outcomes as YLL, the comparison presented here indicated ~3 daily YLL in Nouna and Nairobi with a similar temperature increase. Unfortunately, a direct contrast of results between these two African studies is limited because YLL in Nouna were from NCD only, but from all causes of death in Nairobi.

In Australia and China heat exposure increased the YLL from cardiovascular disease. A total of 45 years were lost daily from cardiovascular disease (95% CI 22 to 67 years) in Brisbane, Australia, at a mean temperature of 32°C versus 24°C [18]. In Guangzhou, China (lag 0-14), a change in mean temperature from the 75th (28°C) to 99th percentile (32°C) resulted in 4.81 (-2.25 to 11.88) daily YLL from cardiovascular disease [20]. Cardiovascular disease contributed to 50% of YLL in Nouna. Although subgroup analysis of NCD was limited by sample size in Nouna, the magnitude of effects was closer to Guangzhou than Brisbane; 4.07 (-2.73 to 35.66) and 7.39 (0.32 to 24.62) mean daily YLLs were found from *all NCD* at lag 0-14 and lag 0-4 respectively at the 50th versus 99th percentile. Heat can exacerbate cardiovascular strain, through increased cardiac output, blood viscosity and coagulation, attenuated vasoconstriction, and cerebral perfusion pressure [22]. Our findings agree with those from Guangzhou and Brisbane [18,20], where heat effects occurred rapidly at lag 0, lasting a maximum of 4 days. In contrast to Brisbane, Nouna and Guangzhou exhibited fewer YLL for a similar age and temperature shift. All sites used regional or local life tables to calculate YLL rather than global life tables, so the elevated YLL in Brisbane are unlikely to be attributable to lower life expectancy in Nouna compared to Brisbane. Unlike Brisbane, the predominant cause of death in Nouna is still infectious disease; most days in the Nouna time series exhibited no YLL from NCD. Temperature-related premature death from NCD could increase in Nouna as the epidemiological transition progresses, increasing the proportion of deaths attributable to NCD in the future.

Daily respiratory YLL increased by 2.81 (-1.54 to 7.16) in Guangzhou at 28°C versus 32°C [20] where infectious and chronic respiratory deaths were grouped together as ICD-10 J00-99. In this analysis, however, chronic respiratory YLL (ICD-10 J30-98) only contributed to 2% of total NCD-YLL in Nouna. The separation of chronic and acute respiratory outcomes maybe relevant for comparing findings from different studies and understanding the causal mechanisms. Digestive, renal and neuropsychiatric causes contributed substantially to overall NCD-YLL in Nouna. Heat is known to trigger renal [23] and mental health-related deaths [24], however, the link to chronic digestive causes requires further investigation.

Although excess NCD-YLL for women was elevated with heat exposure, male NCD-YLL were affected by a greater magnitude at lag 0-2. One explanation is that men working outdoors might have higher exposed to ambient heat. Occupational stress has been associated with excess risk of NCD morbidity including psychological distress[25] and kidney disease [26]. These results are somewhat unexpected considering that women in Nouna are exposed to extra heat from cooking and carrying wood/water for 2-3 hours daily. Women might die prematurely from other causes such as childbirth, leaving men to be more affected by diseases associated with longevity such as cardiovascular disease, however, further investigation of gender differences is warranted.

Contrary to findings across 14 European cities [27], we found no evidence of harvesting effects with heat; gradual reduction in YLL across lag days ensuing the initial surge were not associated with significant subsequent negative associations or a rise again in risk estimates for any subgroups [28]. The public health relevance of our findings is therefore enhanced, as premature NCD mortality is not merely the advancement of death in frail individuals with pre-existing chronic conditions.

This study has several strengths. An 11-year time series of reliable, high-quality data from a rural African setting was used to quantify the burden of temperature on NCD-YLL. Variables such as the date, age and cause of death were subject to quality checks and continuous improvements at International Network for the Demographic Evaluation of Populations and Their Health (INDEPTH) sites including Nouna. These processes enabled one of the best quality and most extensive longituidnal health datasets in Africa and Asia to be used for this study. The DLNM accounted for non-linearity and lagged effects. In place of relative risks which would have been obtained had only death counts been used, combining life expectancy and death counts gave an absolute value for YLL from NCD, which is relevant for policy making [29]. Despite the low number of NCD deaths, significant effects of heat on premature mortality were detected, indicating that the effects were strong. The results in the final model were robust and withstood variations of model parameters. Rather than focusing only on anomalous weather events such as heatwaves, one of the longest time series available in rural Africa was exploited to highlight that excess premature deaths from NCD does not only occur during extreme heat, but with moderate heat.

Some limitations are also noted. Caution should be exercised in generalising these findings to all rural African settings. Temperature data were obtained from the nearest location with a similar temperature profile to Nouna. The lower resolution and distribution of weather data in Burkina Faso compared to Organisation for Economic Co-operation and Development (OECD) countries can make it challenging to obtain suitable weather data in Burkina Faso. Public health scientists ought to address this challenge by extending research beyond where the data are best, to where problems are the greatest and research/solutions most needed. It is likely that cancer or mental disorders were under-reported as sophisticated questionnaires and tests are needed to establish these causes. In 2004, the World Health Organization (WHO) estimated that NCD accounted for 20% of the burden of disease in Burkina Faso as a percentage of total DALYs (disability adjusted life years), which captures both premature death and life lived with disease [30]. We found only 7% of the burden from premature deaths or YLL in Nouna were from NCD. Although the YLL component of DALYs in the WHO estimate were obtained by multiplying the number of deaths at each age by the global standard life expectancy for each age (rather than the regional life expectancy for each age), the sole use of premature death is likely to have missed substantial burden from life lived with disease. Causal studies on the temperature-NCD association would benefit from using DALYs or quality adjusted life years (QALY) as the outcome measure, considering a large proportion of the burden of NCD comes from life lived with disease. The YLL lifetable approach does not differentiate health and sociodemographic risk profiles for each individual. Unfortunately, the sample size was insufficient to further stratify NCD by age (i.e. elderly) or subgroups such as cardiovascular causes. The use of longer time series in the future with larger sample sizes is likely to enable such breakdowns by cause or age, reducing the uncertainty from wide confidence bounds, and supporting better quantification of heat impacts on NCD-YLL.

Conclusion

In rural Sub Saharan Africa, where NCD are not the main cause of premature death, we found that moderate and extreme heat exposure significantly increases excess daily premature mortality from NCD. As NCD prevalence increases in Africa due to demographic, dietary and lifestyle changes, climate change will increasingly contribute as a risk factor towards the burden of deaths from NCD. Subsistence farming communities in Africa, such as Nouna, would therefore benefit from the development of early preventive measures to curb heat-associated NCD deaths.

Competing interests

The authors declare they have no actual or potential competing financial interests

Acknowledgments

We thank Dr David Hondula for help obtaining temperature data from the National Climatic Data Centre, USA, and Drs Adrian Barnett and Cunrui Huang for statistical modelling advice.

Funding

AB was funded by the Klaus-Tschira Stiftung gGmbH (00.128.2008). Funders had no direct role in study design, data collection, data analysis, interpretation or writing of the report.

Data sharing

No additional data are available.

Author contributions

AB and RS developed the research idea with input from JR. Data were provided by AS. AB, MOS, JR and RS developed the modelling strategy. AB conducted the analysis, which was verified by MOS and RJ. AB wrote the manuscript. All authors contributed to revision of the manuscript.

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Disease	Death count	Death (%)	YLL count	YLL (%)
Cardiovascular diseases	461	58	9095	50
Digestive diseases	137	17	3614	20
Malignant neoplasms	81	10	1720	9
Genitourinary diseases	38	5	1602	9
Neuropsychiatric conditions	37	5	1289	7
Congenital anomalies	8	1	481	3
Respiratory diseases	15	2	321	2
Diabetes mellitus	11	1	167	1
Other endocrine disorders	1	0	22	0
Musculoskeletal diseases	1	0	57	0
Total	**790**	**100**	**18367**	**100**

Table 1: Cause specific NCD outcomes with corresponding deaths and years of life lost. NCD accounted for 12% of total deaths, and 7% of total YLL in Nouna between 2000-2010.

	Daily NCD and temperature descriptive statistics 2000-2010					
	Minimum	25%	50%	Mean	75%	Maximum
Daily number of NCD deaths						
Total	0	0	0	0.2	0	5
Male	0	0	0	0.1	0	4
Female	0	0	0	0.1	0	3
>65 years	0	0	0	0.1	0	3
Daily NCD years of life lost						
Total	0	0	0	4.6	0	154
Male	0	0	0	2.4	0	118.9
Female	0	0	0	2.1	0	127.5
>65 years	0	0	0	0.9	0	39.2
Temperature (°C)						
Daily minimum	3.3	21.1	22.8	23.1	25	32.8
Daily average	17.2	27.5	29.2	29.6	31.7	37.8
Daily maximum	22.8	33.3	36.4	36.1	38.9	43.9

Table 2: Summary statistics of daily NCD deaths, NCD years of life lost and temperature in Nouna, Burkina Faso between 2000-2010.

	27.8°C (1st percentile)	30°C (5th percentile)	31.1°C (10th percentile)	33.3°C (25th percentile)	38.9°C (75th percentile)	41.4°C (90th percentile)	41.7°C (95th percentile)	42.8°C (99th percentile)
	34 days below 27.8°C	174 days below 30°C	325 days below 31.3°C	912 days below 33.3°C	883 days above 38.9°C	300 days above 41.4°C	189 days above 41.7°C	28 days above 42.8°C
	RR (95% CI)	RR (95% CI)	RR (95% CI)	RR (95% CI)	RR (95% CI)	RR (95% CI)	RR (95% CI)	RR (95% CI)
Lag structure 0-4								
All age	0.54 (0.22 to 1.36)	0.82 (0.56 to 1.21)	0.93 (0.72 to 1.21)	1.00 (0.99 to 1.01)	1.29 (0.81 to 2.04)	1.96 (1.05 to 3.67)	2.08 (1.08 to 4.01)	2.61 (1.07 to 6.35)
Male	0.53 (0.15 to 1.86)	0.77 (0.46 to 1.3)	0.88 (0.62 to 1.25)	1.00 (0.99 to 1.01)	1.36 (0.74 to 2.49)	2.56 (1.14 to 5.75)	2.86 (1.23 to 6.69)	4.60 (1.45 to 14.64)
Female	0.38 (0.10 to 1.41)	0.81 (0.47 to 1.4)	0.99 (0.68 to 1.43)	1.00 (0.99 to 1.01)	1.05 (0.54 to 2.04)	1.20 (0.49 to 2.98)	1.19 (0.46 to 3.05)	1.06 (0.30 to 3.79)
Lag structure 0-14								
All age	0.89 (0.22 to 3.67)	0.94 (0.53 to 1.65)	0.96 (0.64 to 1.42)	1.00 (0.99 to 1.01)	1.65 (0.82 to 3.35)	1.98 (0.71 to 5.54)	1.98 (0.66 to 5.91)	1.88 (0.41 to 8.75)
Male	0.71 (0.11 to 4.63)	0.91 (0.43 to 1.94)	0.97 (0.57 to 1.66)	1.00 (0.99 to 1.01)	1.57 (0.62 to 3.97)	2.11 (0.57 to 7.85)	2.14 (0.53 to 8.70)	2.16 (0.29 to 16.35)
Female	1.24 (0.16 to 9.27)	1.09 (0.49 to 2.46)	1.05 (0.59 to 1.84)	1.00 (0.98 to 1.02)	1.42 (0.50 to 3.99)	1.28 (0.28 to 5.97)	1.21 (0.24 to 6.17)	0.92 (0.10 to 8.30)

Table 3a: Cumulative relative risk (and 95% confidence bounds) of maximum temperature on non-communicable disease years of life lost in Nouna stratified across lag 0-4 and lag 0-14 days and gender between 2000-2010. Relative risks are presented for; heat effects as 38.9°C, 41.1°C and 41.7°C with reference to 36.4°C; cold effects as 30°C, 31.1°C and 33.3°C with reference to 36.4°C. Results controlled for long-term trends, season, day of the week, and heaping effect.

	27.8°C (1st percentile)	30°C (5th percentile)	31.1°C (10th percentile)	33.3°C (25th percentile)	38.9°C (75th percentile)	41.4°C (90th percentile)	41.7°C (95th percentile)	42.8°C (99th percentile)
	34 days below 27.8°C	174 days below 30°C	325 days below 31.3°C	912 days below 33.3°C	883 days above 38.9°C	300 days above 41.4°C	189 days above 41.7°C	28 days above 42.8°C
	YLL (95% CI)	YLL (95% CI)	YLL (95% CI)	YLL (95% CI)	YLL (95% CI)	YLL (95% CI)	YLL (95% CI)	YLL (95% CI)
Lag structure 0-4								
All age	-2.11 (-3.61 to 1.64)	-0.81 (-2.02 to 0.97)	-0.31 (-1.30 to 0.97)	0.00 (-0.03 to 0.03)	1.33 (-0.86 to 4.80)	4.44 (0.24 to 12.28)	4.98 (0.38 to 13.83)	7.39 (0.32 to 24.62)
Male	-1.13 (-2.04 to 2.06)	-0.55 (-1.30 to 0.72)	-0.29 (-0.92 to 0.59)	0.00 (-0.03 to 0.02)	0.86 (-0.62 to 3.57)	3.73 (0.33 to 11.39)	4.48 (0.54 to 13.65)	8.65 (1.07 to 32.73)
Female	-1.30 (-1.88 to 0.86)	-0.39 (-1.11 to 0.85)	-0.03 (-0.66 to 0.90)	0.01 (-0.01 to 0.03)	0.10 (-0.97 to 2.19)	0.43 (-1.08 to 4.16)	0.39 (-1.13 to 4.32)	0.12 (-1.48 to 5.86)
Lag structure 0-14								
All age	-0.48 (-3.6 to 12.27)	-0.28 (-2.15 to 3.01)	-0.20 (-1.64 to 1.95)	-0.01 (-0.06 to 0.04)	3.01 (-0.84 to 10.82)	4.53 (-1.33 to 20.89)	4.5 (-1.55 to 22.57)	4.07 (-2.73 to 35.66)
Male	-0.70 (-2.14 to 8.71)	-0.21 (-1.37 to 2.25)	-0.06 (-1.03 to 1.58)	0.00 (-0.04 to 0.04)	1.38 (-0.90 to 7.12)	2.67 (-1.03 to 16.44)	2.74 (-1.14 to 18.48)	2.78 (-1.72 to 36.83)
Female	0.50 (-1.75 to 17.37)	0.20 (-1.08 to 3.07)	0.09 (-0.86 to 1.77)	0.00 (-0.03 to 0.03)	0.87 (-1.05 to 6.28)	0.59 (-1.52 to 10.44)	0.44 (-1.60 to 10.86)	-0.18 (-1.89 to 15.32)

Table 3b: Cumulative excess average daily NCD-YLL (and 95% confidence bounds) stratified across lag 0-4 and lag 0-14 days and gender between 2000-2010. Relative risks were used to calculate excess average daily NCD-YLL as follows: (Average daily NCD-YLL of all-age, male or female * relative risk) – Average daily NCD-YLL. NCD-YLL are presented for; heat effects as 42.8°C, 38.9°C, 41.1°C and 41.7°C with reference to 36.4°C; cold effects as 30°C, 31.1°C, 33.3°C and 27.8°C with reference to 36.4°C. Results controlled for long-term trends, season, day of the week, and heaping effect.

	All age		Male		Female	
	30°C (5th percentile)	41.7°C (95th percentile)	30°C (5th percentile)	41.7°C (95th percentile)	30°C (5th percentile)	41.7°C (95th percentile)
	RR (95% CI)		RR (95% CI)		RR (95% CI)	
lag0	0.96 (0.89 to 1.04)	1.18 (1.03 to 1.35)	0.96 (0.87 to 1.07)	1.24 (1.04 to 1.48)	0.96 (0.86 to 1.08)	1.07 (0.88 to 1.30)
lag1	0.97 (0.90 to 1.04)	1.16 (1.03 to 1.31)	0.97 (0.88 to 1.06)	1.21 (1.04 to 1.42)	0.97 (0.88 to 1.07)	1.06 (0.89 to 1.27)
lag2	0.97 (0.91 to 1.04)	1.14 (1.02 to 1.27)	0.97 (0.9 to 1.05)	1.19 (1.03 to 1.36)	0.98 (0.89 to 1.07)	1.05 (0.90 to 1.24)
lag3	0.98 (0.92 to 1.03)	1.12 (1.01 to 1.23)	0.98 (0.91 to 1.05)	1.16 (1.02 to 1.31)	0.98 (0.91 to 1.06)	1.05 (0.91 to 1.21)
lag4	0.98 (0.94 to 1.03)	1.10 (1.01 to 1.20)	0.98 (0.92 to 1.05)	1.13 (1.01 to 1.27)	0.99 (0.92 to 1.06)	1.04 (0.91 to 1.18)
lag5	0.99 (0.94 to 1.03)	1.08 (1.00 to 1.17)	0.99 (0.93 to 1.04)	1.10 (1.00 to 1.22)	0.99 (0.93 to 1.06)	1.03 (0.91 to 1.16)
lag6	0.99 (0.95 to 1.03)	1.06 (0.99 to 1.15)	0.99 (0.94 to 1.04)	1.08 (0.98 to 1.19)	1.00 (0.94 to 1.06)	1.02 (0.91 to 1.14)
lag7	1.00 (0.96 to 1.03)	1.05 (0.97 to 1.13)	0.99 (0.95 to 1.05)	1.05 (0.96 to 1.16)	1.01 (0.95 to 1.06)	1.01 (0.91 to 1.13)
lag8	1.00 (0.96 to 1.04)	1.03 (0.96 to 1.11)	1.00 (0.95 to 1.05)	1.03 (0.93 to 1.13)	1.01 (0.96 to 1.07)	1 .00 (0.90 to 1.12)
lag9	1.00 (0.96 to 1.05)	1.01 (0.94 to 1.10)	1.00 (0.95 to 1.06)	1.00 (0.91 to 1.11)	1.02 (0.96 to 1.08)	1 .00 (0.89 to 1.12)
lag10	1.01 (0.96 to 1.06)	1.00 (0.91 to 1.09)	1.01 (0.95 to 1.07)	0.98 (0.88 to 1.09)	1.02 (0.96 to 1.09)	0.99 (0.87 to 1.12)
lag11	1.01 (0.96 to 1.07)	0.98 (0.89 to 1.08)	1.01 (0.94 to 1.08)	0.96 (0.85 to 1.08)	1.03 (0.96 to 1.11)	0.98 (0.85 to 1.13)
lag12	1.02 (0.96 to 1.08)	0.96 (0.86 to 1.07)	1.02 (0.94 to 1.10)	0.93 (0.81 to 1.07)	1.04 (0.96 to 1.12)	0.97 (0.83 to 1.14)
lag13	1.02 (0.96 to 1.09)	0.95 (0.84 to 1.07)	1.02 (0.93 to 1.12)	0.91 (0.78 to 1.06)	1.04 (0.95 to 1.14)	0.97 (0.81 to 1.15)
lag14	1.03 (0.96 to 1.11)	0.93 (0.82 to 1.06)	1.03 (0.93 to 1.13)	0.89 (0.75 to 1.06)	1.05 (0.95 to 1.16)	0.96 (0.79 to 1.16)

Table 4a: Relative risk (and 95% confidence bounds) of maximum temperature on non-communicable disease years of life lost in Nouna stratified by individual lag days for all age, males and females between 2000-2010. Relative risks are presented for heat effects as 41.7°C (95th percentile) with reference to 36.4°C, cold effects as 30°C (5th percentile) with reference to 36.4°C. Results controlled for long-term trends, season, day of the week, and heaping effect.

	All age		Male		Female	
	30°C (5th percentile)	**41.7°C (95th percentile)**	**30°C (5th percentile)**	**41.7°C (95th percentile)**	**30°C (5th percentile)**	**41.7°C (95th percentile)**
	174 days below 30°C	189 days above 41.7°C	174 days below 30°C	189 days above 41.7°C	174 days below 30°C	189 days above 41.7°C
	YLL (95% CI)		YLL (95% CI)		YLL (95% CI)	
lag0	-0.16 (-0.50 to 0.20)	0.81 (0.13 to 1.59)	-0.09 (-0.31 to 0.16)	0.58 (0.11 to 1.15)	-0.08 (-0.29 to 0.16)	0.15 (-0.25 to 0.63)
lag1	-0.14 (-0.45 to 0.19)	0.72 (0.12 to 1.41)	-0.08 (-0.28 to 0.15)	0.51 (0.09 to 1.01)	-0.06 (-0.26 to 0.15)	0.13 (-0.23 to 0.56)
lag2	-0.12 (-0.40 to 0.17)	0.63 (0.09 to 1.24)	-0.07 (-0.25 to 0.13)	0.44 (0.07 to 0.87)	-0.05 (-0.23 to 0.14)	0.11 (-0.21 to 0.50)
lag3	-0.10 (-0.35 to 0.16)	0.55 (0.07 to 1.08)	-0.06 (-0.22 to 0.12)	0.38 (0.05 to 0.75)	-0.04 (-0.20 to 0.13)	0.10 (-0.20 to 0.43)
lag4	-0.08 (-0.30 to 0.15)	0.46 (0.04 to 0.93)	-0.05 (-0.19 to 0.11)	0.31 (0.02 to 0.64)	-0.03 (-0.17 to 0.13)	0.08 (-0.19 to 0.38)
lag5	-0.06 (-0.25 to 0.14)	0.38 (0.00 to 0.79)	-0.04 (-0.17 to 0.10)	0.25 (-0.01 to 0.54)	-0.01 (-0.14 to 0.12)	0.06 (-0.18 to 0.33)
lag6	-0.04 (-0.22 to 0.14)	0.30 (-0.06 to 0.68)	-0.03 (-0.15 to 0.10)	0.19 (-0.05 to 0.45)	0.00 (-0.12 to 0.12)	0.04 (-0.18 to 0.30)
lag7	-0.02 (-0.19 to 0.16)	0.21 (-0.12 to 0.58)	-0.01 (-0.13 to 0.11)	0.12 (-0.10 to 0.37)	0.01 (-0.10 to 0.13)	0.03 (-0.19 to 0.27)
lag8	0.00 (-0.17 to 0.18)	0.13 (-0.20 to 0.50)	0.00 (-0.12 to 0.12)	0.07 (-0.16 to 0.31)	0.03 (-0.09 to 0.14)	0.01 (-0.21 to 0.26)
lag9	0.02 (-0.16 to 0.21)	0.06 (-0.30 to 0.44)	0.01 (-0.12 to 0.14)	0.01 (-0.22 to 0.26)	0.04 (-0.08 to 0.17)	-0.01 (-0.24 to 0.25)
lag10	0.04 (-0.16 to 0.26)	-0.02 (-0.40 to 0.39)	0.02 (-0.13 to 0.17)	-0.05 (-0.30 to 0.23)	0.05 (-0.08 to 0.19)	-0.02 (-0.27 to 0.26)
lag11	0.06 (-0.17 to 0.31)	-0.10 (-0.51 to 0.36)	0.03 (-0.14 to 0.20)	-0.10 (-0.37 to 0.2)	0.07 (-0.08 to 0.22)	-0.04 (-0.31 to 0.27)
lag12	0.08 (-0.18 to 0.36)	-0.17 (-0.62 to 0.33)	0.04 (-0.15 to 0.24)	-0.16 (-0.45 to 0.17)	0.08 (-0.09 to 0.26)	-0.06 (-0.35 to 0.29)
lag13	0.11 (-0.19 to 0.42)	-0.25 (-0.74 to 0.31)	0.05 (-0.16 to 0.28)	-0.21 (-0.52 to 0.15)	0.09 (-0.10 to 0.30)	-0.07 (-0.40 to 0.31)
lag14	0.13 (-0.21 to 0.49)	-0.32 (-0.85 to 0.29)	0.06 (-0.17 to 0.32)	-0.26 (-0.60 to 0.13)	0.11 (-0.11 to 0.34)	-0.09 (-0.44 to 0.34)

Table 4b: Excess average daily NCD-YLL (and 95% confidence bounds) in Nouna stratified by individual lag days for all age, males and females between 2000-2010. Relative risks were used to calculate excess average daily NCD-YLL as follows: (Average daily NCD-YLL of all-age, male or female * relative risk) – Average daily NCD-YLL. NCD-YLL are presented for heat effects as 41.7°C (95th percentile) with reference to 36.4°C, cold effects as 30°C (5th percentile) with reference to 36.4°C. Results controlled for long-term trends, season, day of the week, and heaping effect.

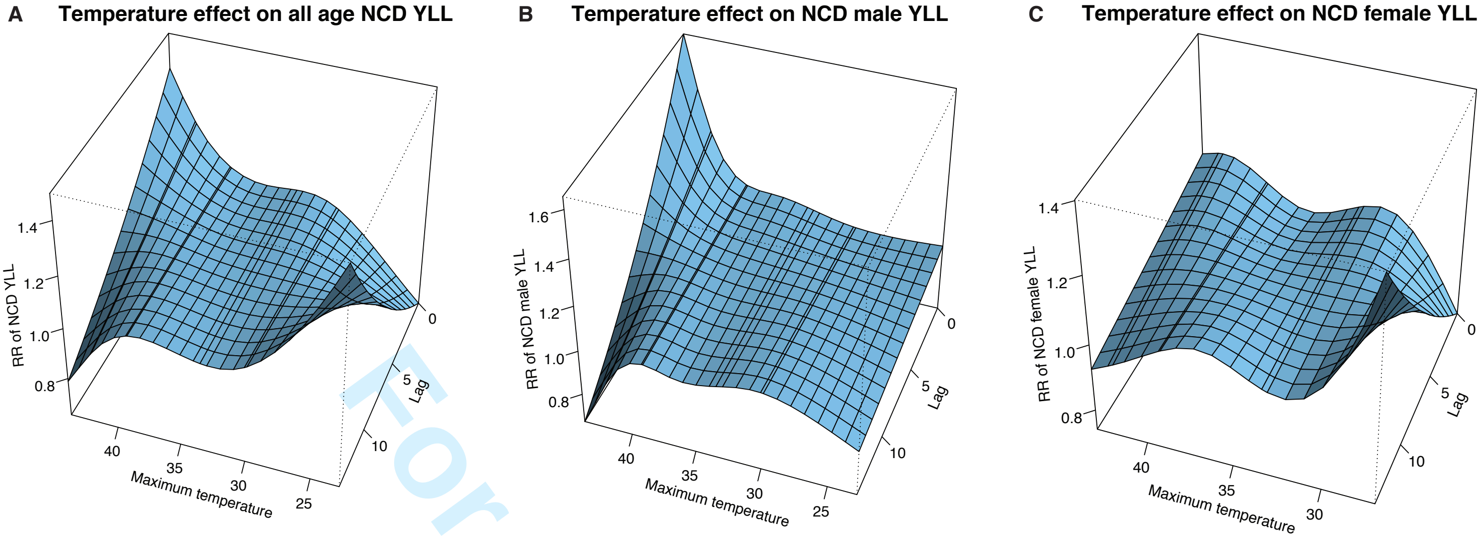


Figure 1: Association of RR of NCD-YLL to maximum temperature and lag days, with reference to 36.4°C for all ages, males and females.

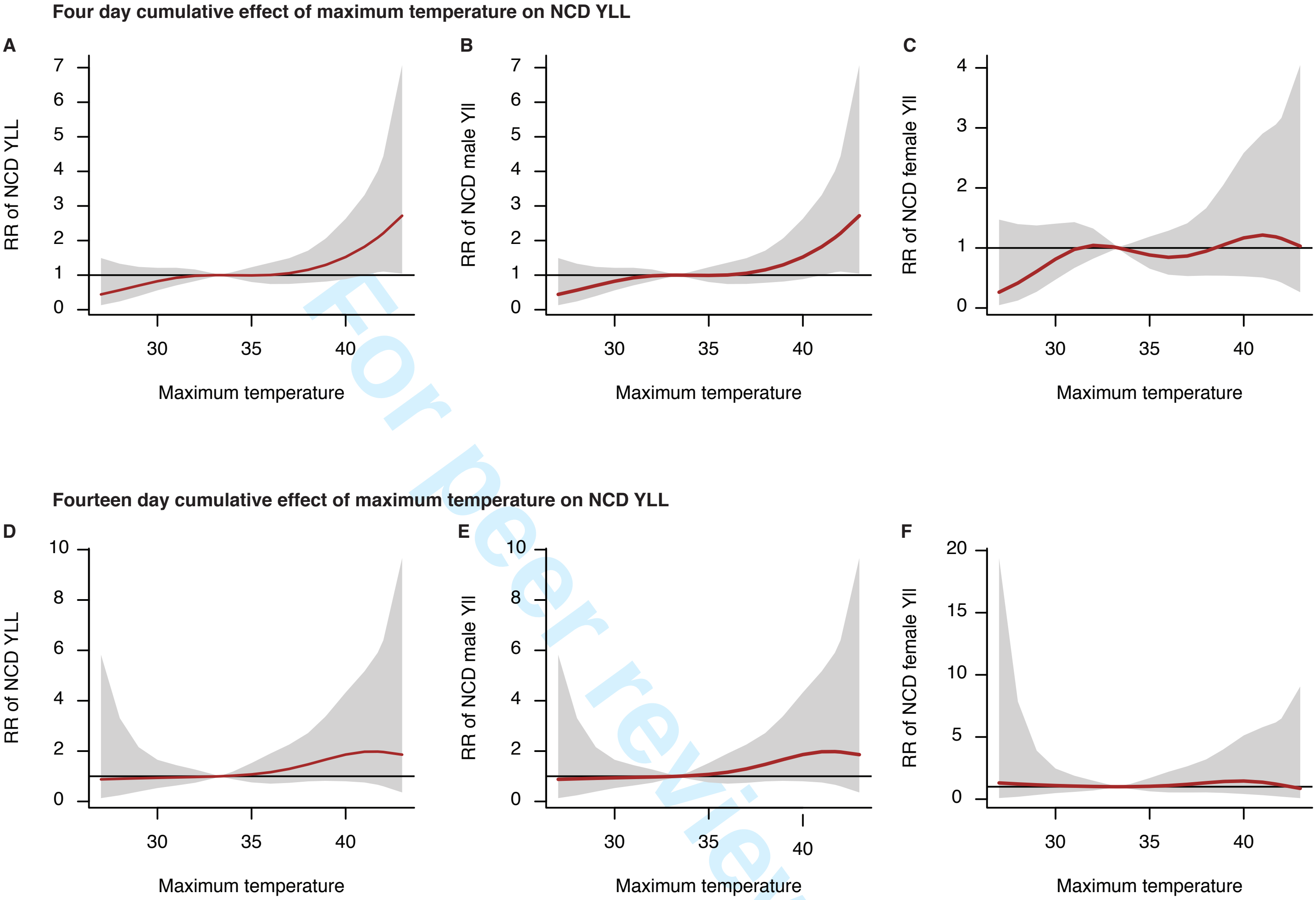


Figure 2: Plots of 4-day (panel A-all age, B-male, and C-female), and 14-day (panel D-all age, E-male, and F-female) cumulative RR of NCD-YLL against maximum temperature (solid line) with 95% confidence bounds (grey area) for all ages, males and females in Nouna, Burkina Faso between 2000 and 2010. The reference temperature is 36.4°C. Note: to improve readability of the curves, the scales on the y-axis differ.

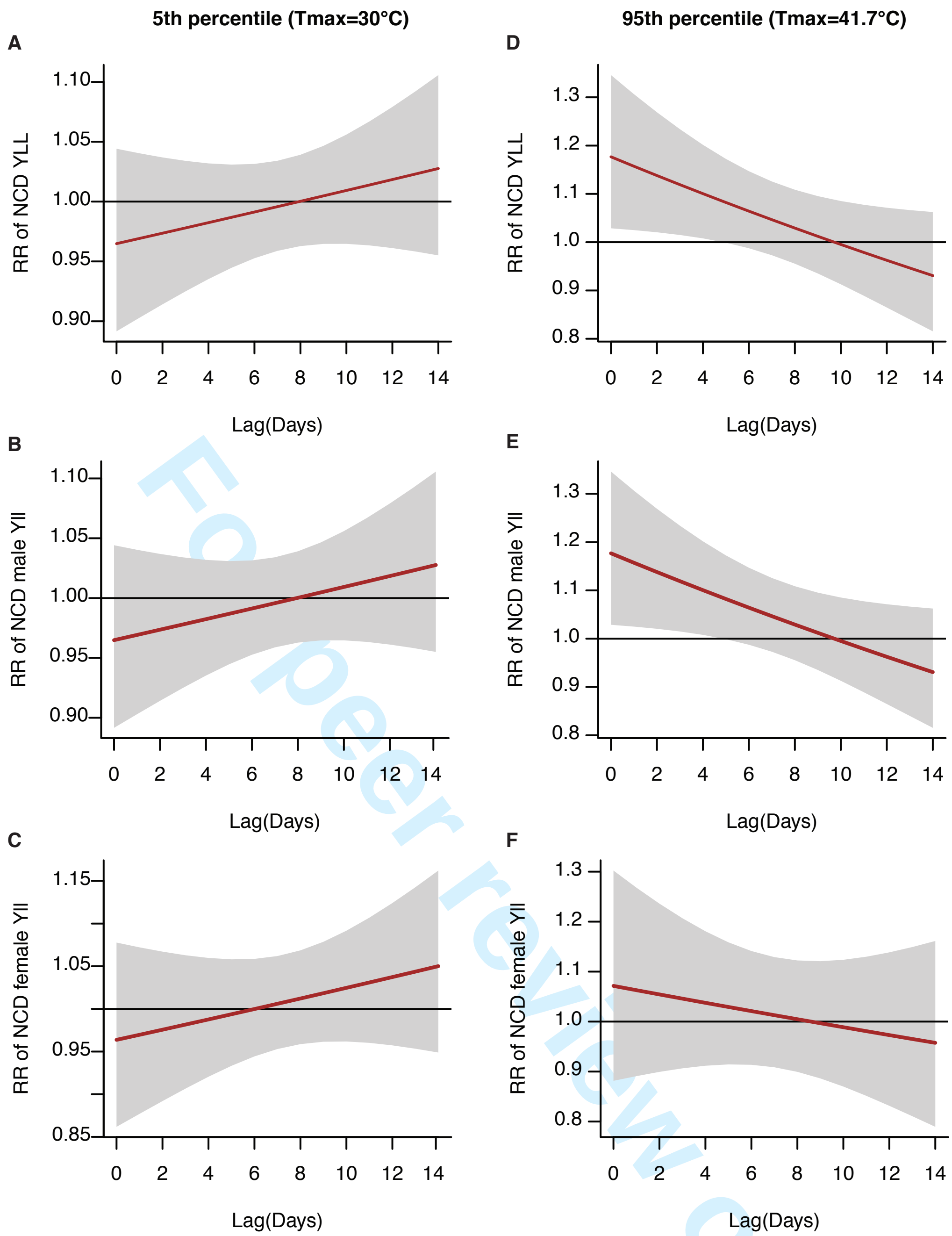


Figure 3: Delayed effects of maximum temperature on the RR of NCD-YLL (solid line) and 95% confidence bounds (grey area) for all age, males and females in Nouna, Burkina Faso, by lag 0-14 days. Plots A-all age, B-male, and C-female represent cold effects at 30°C (5th percentile), and plots D-all age, E-male, and F-female represent heat effects at 41.7°C (95th percentile) of maximum temperature. The reference temperature is 36.4°C. Note: to improve readability of the curves, the scales on the y-axis differ.

Supplementary File

Excess burden of non-communicable disease years of life lost from heat in rural Burkina Faso: a time-series analysis of the years 2000-2010

Aditi Bunker, Maquins Odhiambo Sewe, Ali Sie, Joacim Rocklöv, Rainer Sauerborn

Nouna life table development with *R* software

Vital statistics including the unique identifying number (ID), date of birth, date of immigration into the HDSS, date of death, date of emigration from the HDSS and gender were used to calculate age standardized death rates (ASDR) separately for males and females. The gender-specific ASDRs were used to generate mean additional survival time for each respective age band.

Supplementary Table 1: Male life table for the Nouna population.

Age group	Male ASDR	Conditional probabilities of death in age interval (Initial)	Number of people having Xth birthday	Total number of deaths in age interval	Total number of person years spent in age interval	Total number of persons years lived by those aged x and over	Male mean additional survival time at age X	nax---Initial	Interval
[0-1]	0.05174	0.0493	100000	4934	95362	5801098	58.0	0.06	1
[1-5)	0.02025	0.0773	95066	7349	362877	5705736	60.0	1.634	4
[5-9)	0.00271	0.0135	87717	1181	435636	5342858	60.9	2.500	5
[10-14)	0.00169	0.0084	86537	728	430865	4907223	56.7	2.500	5
[15-19)	0.00213	0.0106	85809	908	427128	4476357	52.2	2.888	5
[20-24)	0.00197	0.0098	84901	834	422516	4049229	47.7	2.614	5
[25-29)	0.00268	0.0133	84067	1121	417549	3626714	43.1	2.513	5
[30-34)	0.00375	0.0186	82947	1540	410920	3209164	38.7	2.525	5
[35-39)	0.00670	0.0329	81406	2682	400487	2798244	34.4	2.560	5
[40-44)	0.00718	0.0353	78724	2779	386943	2397757	30.5	2.597	5
[45-49)	0.01037	0.0506	75945	3844	370750	2010814	26.5	2.665	5
[50-54)	0.01373	0.0666	72101	4799	349454	1640064	22.7	2.697	5
[55-59)	0.01989	0.0951	67302	6401	321795	1290611	19.2	2.701	5
[60-64)	0.02682	0.1263	60901	7694	286842	968815	15.9	2.704	5
[65-69)	0.03897	0.1787	53208	9508	244007	681974	12.8	2.683	5
[70-74)	0.06415	0.2786	43699	12175	189788	437966	10.0	2.642	5
[75-79)	0.09484	0.3858	31524	12163	128247	248179	7.9	2.585	5
[80-84)	0.13669	0.5099	19361	9873	72223	119932	6.2	2.510	5
85+	0.19889	1.0000	9489	9489	47709	47709	5.0	2.351	5

Supplementary Table 2: Female life table for the Nouna population.

Age group	Female ASDR	Conditional probabilities of death in age interval (Initial)	Number of people having Xth birthday	Total number of deaths in age interval	Total number of person years spent in age interval	Total number of persons years lived by those aged x and over	Female mean additional survival time at age X	nax---Initial	Interval
[0-1]	0.04829	0.0462	100000	4619	95658	6151128	61.5	0.06	1
[1-5)	0.01761	0.0676	95381	6449	366267	6055469	63.5	1.634	4
[5-9)	0.00253	0.0125	88932	1116	441872	5689203	64.0	2.500	5
[10-14)	0.00154	0.0077	87817	672	437402	5247331	59.8	2.500	5
[15-19)	0.00231	0.0115	87144	1002	433606	4809928	55.2	2.888	5
[20-24)	0.00221	0.0110	86143	948	428451	4376323	50.8	2.614	5
[25-29)	0.00407	0.0201	85194	1715	421707	3947872	46.3	2.513	5
[30-34)	0.00449	0.0222	83479	1854	412808	3526165	42.2	2.525	5
[35-39)	0.00463	0.0229	81625	1868	403569	3113358	38.1	2.560	5
[40-44)	0.00555	0.0274	79758	2182	393543	2709789	34.0	2.597	5
[45-49)	0.00589	0.0291	77575	2255	382609	2316245	29.9	2.665	5
[50-54)	0.01040	0.0508	75320	3823	367794	1933636	25.7	2.697	5
[55-59)	0.01283	0.0623	71496	4454	347242	1565842	21.9	2.701	5
[60-64)	0.01747	0.0840	67042	5631	322284	1218600	18.2	2.704	5
[65-69)	0.03271	0.1520	61412	9337	285425	896316	14.6	2.683	5
[70-74)	0.05247	0.2335	52075	12157	231707	610891	11.7	2.642	5
[75-79)	0.08025	0.3361	39918	13417	167186	379184	9.5	2.585	5
[80-84)	0.10647	0.4208	26500	11151	104736	211998	8.0	2.510	5
85+	0.14310	1.0000	15349	15349	107261	107261	7.0	2.351	5

The mean additional survival time from the life table was matched by age and sex to calculated NCD YLL. An excerpt of the *R* code is given here:

```
## Calculate NCD male YLL
data$yllncd[age<1  & sex=="M" & broadgroup=="NCD"]            <-58.0
data$yllncd[age>=1 & age<=5  & sex=="M"&$broadgroup=="NCD"]   <-60.0
data$yllncd[age>5  & age<=10 & sex=="M"&$broadgroup=="NCD"]   <-60.9
data$yllncd[age>10 & age<=15 & sex=="M" & $broadgroup=="NCD"] <-56.7
data$yllncd[age>15 & age<=20 & sex=="M" & $broadgroup=="NCD"] <-52.2
data$yllncd[age>20 & age<=25 & sex=="M" & $broadgroup=="NCD"] <-47.7
data$yllncd[age>25 & age<=30 & sex=="M" & $broadgroup=="NCD"] <-43.1
data$yllncd[age>30 & age<=35 & sex=="M" & $broadgroup=="NCD"] <-38.7
data$yllncd[age>35 & age<=40 & sex=="M" & broadgroup=="NCD"]  <-34.4
data$yllncd[age>40 & age<=45 & sex=="M" & broadgroup=="NCD"]  <-30.5
data$yllncd[age>45 & age<=50 & sex=="M" & broadgroup=="NCD"]  <-26.5
data$yllncd[age>50 & age<=55 & sex=="M" & broadgroup=="NCD"]  <-22.7
data$yllncd[age>55 & age<=60 & sex=="M" & broadgroup=="NCD"]  <-19.2
data$yllncd[age>60 & age<=65 & sex=="M" & broadgroup=="NCD"]  <-15.9
data$yllncd[age>65 & age<=70 & sex=="M" & broadgroup=="NCD"]  <-12.8
data$yllncd[age>70 & age<=75 & sex=="M" & broadgroup=="NCD"]  <-10.0
data$yllncd[age>75 & age<=80 & sex=="M" & broadgroup=="NCD"]  <- 7.9
data$yllncd[age>80 & age<=85 & sex=="M" & broadgroup=="NCD"]  <- 6.2
data$yllncd[age>85 & sex=="M" & broadgroup=="NCD"]            <- 5.0

## Calculate NCD female YLL
data$yllncd[age< 1 & sex=="F" & broadgroup=="NCD"]            <-61.5
data$yllncd[age>=1 & age<= 5 & sex=="F" & broadgroup=="NCD"]  <-63.5
data$yllncd[age> 5 & age<=10 & sex=="F" & broadgroup=="NCD"]  <-64.0
data$yllncd[age>10 & age<=15 & sex=="F" & broadgroup=="NCD"]  <-59.8
data$yllncd[age>15 & age<=20 & sex=="F" & broadgroup=="NCD"]  <-55.2
data$yllncd[age>20 & age<=25 & sex=="F" & broadgroup=="NCD"]  <-50.8
data$yllncd[age>25 & age<=30 & sex=="F" & broadgroup=="NCD"]  <-46.3
data$yllncd[age>30 & age<=35 & sex=="F" & broadgroup=="NCD"]  <-42.2
data$yllncd[age>35 & age<=40 & sex=="F" & broadgroup=="NCD"]  <-38.1
data$yllncd[age>40 & age<=45 & sex=="F" & broadgroup=="NCD"]  <-34.0
data$yllncd[age>45 & age<=50 & sex=="F" & broadgroup=="NCD"]  <-29.9
data$yllncd[age>50 & age<=55 & sex=="F" & broadgroup=="NCD"]  <-25.7
data$yllncd[age>55 & age<=60 & sex=="F" & broadgroup=="NCD"]  <-21.9
data$yllncd[age>60 & age<=65 & sex=="F" & broadgroup=="NCD"]  <-18.2
```

```
data$yllncd[age>65 & age<=70 & sex=="F" & broadgroup=="NCD"]  <-14.6
data$yllncd[age>70 & age<=75 & sex=="F" & broadgroup=="NCD"]  <-11.7
data$yllncd[age>75 & age<=80 & sex=="F" & broadgroup=="NCD"]  <- 9.5
data$yllncd[age>80 & age<=85 & sex=="F" & broadgroup=="NCD"]  <- 8.0
data$yllncd[age>85 & sex=="F" & broadgroup=="NCD"]            <- 7.0
```

Exploratory analysis

Exploratory analysis of NCD deaths and YLL stratified by year indicates that 2010, 2008 and 2001 recorded the highest number of NCD deaths and YLL.

Supplementary Table 3: Breakdown of NCD deaths and YLL by year.

	All-age		Male		Female		65+ Years	
Year	NCD deaths	NCD YLL	NCD deaths	NCD YLL	NCD deaths	NCD YLL	NCD deaths	NCD YLL
2000	45	1180.2	29	688.9	16	491.3	19	192
2001	86	2130.1	49	1253.1	37	877	38	405.3
2002	51	1229.9	24	565.7	27	664.2	23	236.1
2003	67	1697.6	34	864.1	33	833.5	28	278.9
2004	57	1141.8	32	640.1	25	501.7	31	313.9
2005	71	1618.7	34	598.9	37	1019.8	29	280.6
2006	77	1758.6	41	897.8	36	860.8	40	413.5
2007	71	1807.6	42	1076.5	29	731.1	29	288.5
2008	86	1894.2	52	1222.9	34	671.3	43	440.3
2009	75	1632.6	45	987.7	30	644.9	28	307.2
2010	104	2275.2	52	1036.5	52	1238.7	48	455.2
Total	790	18366.5	434	9832.2	356	8534.3	356	3611.5

Further stratification of NCD deaths and YLL by month shows that NCD-YLL are the greatest between November and April.

Supplementary Table 4: Breakdown of NCD deaths and YLL by month.

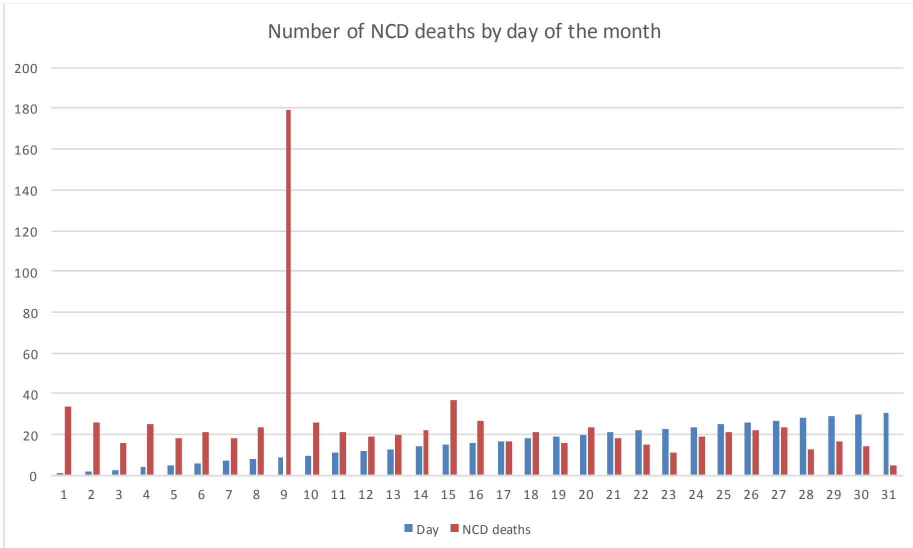
	Total		Male		Female		65+ Years	
Month	NCD deaths	NCD YLL	NCD deaths	NCD YLL	NCD deaths	NCD YLL	NCD deaths	NCD YLL
Jan	71	1606.3	32	683.1	39	923.2	36	387
Feb	75	1492.5	42	855	33	637.5	38	414.5
Mar	62	1157.2	32	536.9	30	620.3	32	298.4
Apr	73	1420.1	39	726.1	34	694	42	408.1
May	66	1619.4	44	1010.1	22	609.3	26	232.3
Jun	69	1913.9	37	964.6	32	949.3	25	243.8
Jul	58	1456.2	30	710.4	28	745.8	26	275.9
Aug	59	1536.6	31	842.3	28	694.3	21	229.8
Sep	65	1641.6	34	796.6	31	845	23	241.2
Oct	52	1252.3	31	790.4	21	461.9	24	242
Nov	59	1414.1	37	886	22	528.1	29	315.2
Dec	81	1856.3	45	1030.7	36	825.6	34	323.3
Total	790	18366.5	434	9832.2	356	8534.3	356	3611.5

A heaping effect can be found on the 9th day of every month.

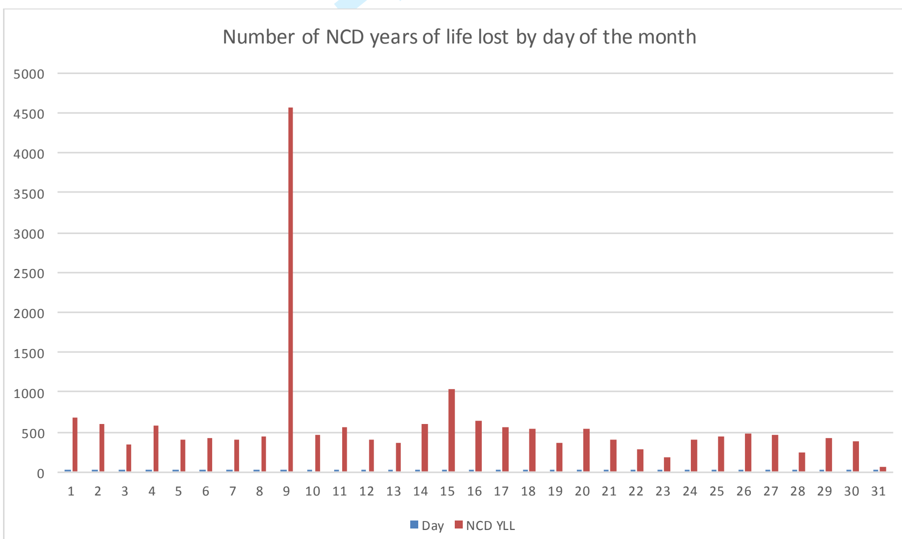
Supplementary Table 5: Breakdown of NCD deaths and YLL by day.

	Total		Male		Female		65+ Years	
Day	NCD deaths	NCD YLL	NCD deaths	NCD YLL	NCD deaths	NCD YLL	NCD deaths	NCD YLL
1	34	677.6	19	326.5	15	351.1	15	165.1
2	26	602.7	8	183.4	18	419.3	13	143.2
3	16	337	10	199.5	6	137.5	7	59.8
4	25	591.7	10	230.2	15	361.5	10	100.5
5	18	408.7	13	220.5	5	188.2	8	78.8
6	21	430.2	11	257.9	10	172.3	12	115
7	18	409.1	9	196	9	213.1	8	79.7
8	24	442.9	16	333.2	8	109.7	13	114.9
9	179	4559	96	2325.4	83	2233.6	77	763.2
10	26	471.6	15	274.2	11	197.4	14	140.7
11	21	560.2	7	120.8	14	439.4	10	99.2
12	19	408.3	14	271.9	5	136.4	10	117.2
13	20	374	12	209.2	8	164.8	12	106.9
14	22	607.5	12	387.5	10	220	9	112.4
15	37	1033.6	25	733.1	12	300.5	6	47.8
16	27	646	16	385.4	11	260.6	7	71.4
17	17	569.4	10	361.5	7	207.9	4	36
18	21	533.7	13	302.1	8	231.6	9	107.4
19	16	364.6	6	203.3	10	161.3	7	79
20	24	543.5	10	224.6	14	318.9	13	159.9
21	18	402.8	11	244.5	7	158.3	11	108.5
22	15	280.6	10	221.4	5	59.2	11	113.4
23	11	181.8	8	107.8	3	74	7	68.1
24	19	414.2	11	179.9	8	234.3	9	79
25	21	448.2	10	214.1	11	234.1	11	100.7
26	22	486.1	13	306	9	180.1	6	63.9
27	24	458.7	14	293.1	10	165.6	12	116.5
28	13	243.2	6	95.6	7	147.6	9	101.4
29	17	423.7	7	130.9	10	292.8	6	57.5
30	14	386.8	10	282.7	4	104.1	6	65.2
31	5	69.1	2	10	3	59.1	4	39.2
Total	790	18366.5	434	9832.2	356	8534.3	356	3611.5

The histogram of number of NCD deaths and corresponding NCD-YLL stratified by day of the month reveals a heaping effect on 9th of every month. We control for this effect in the statistical modeling.



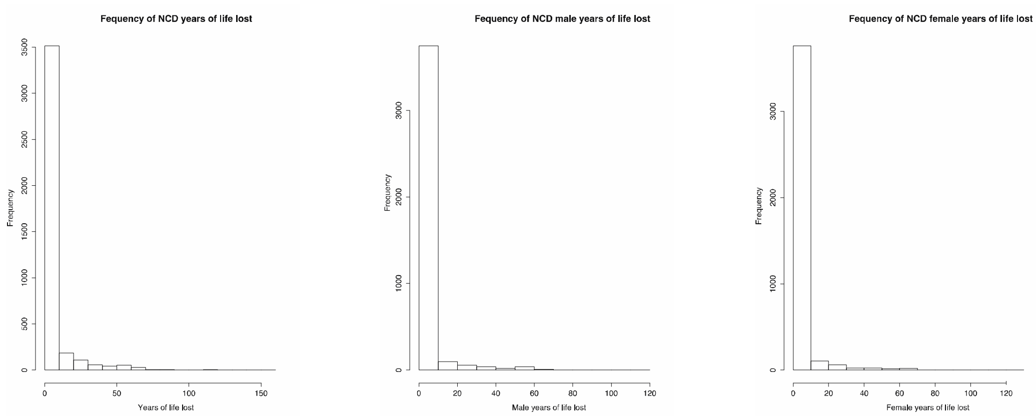
Supplementary Figure 1: Count of NCD deaths by day.



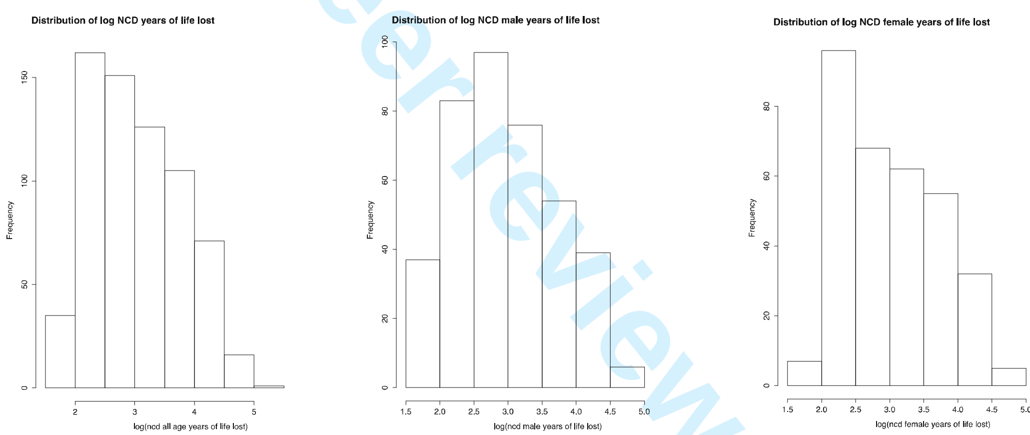
Supplementary Figure 2: Count of NCD-YLL by day.

Statistical modeling

The histrogram reveals that for most days (represented by 'Frequency' on the y axis) there were no NCD-YLL.

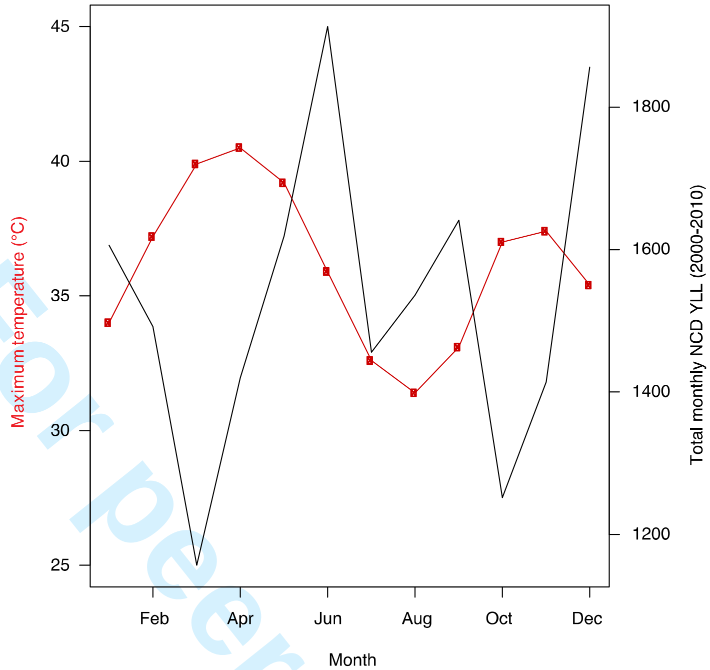


Supplementary Figure 3: Frequency of NCD-YLL for all-age, males and females.



Supplementary Figure 4: Distribution of log NCD-YLL for all-age, males and females.

The plot of monthly maximum temperature and NCD YLL (2000-2010) shows that the peak in maximum temperature is associated with a trough in NCD YLL.

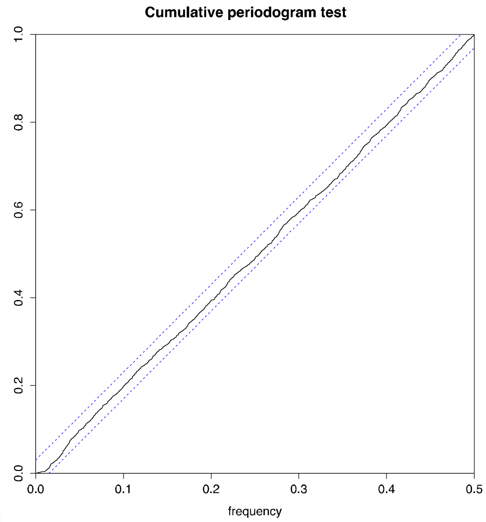


Supplementary Figure 5: Correlation between monthly maximum temperature and NCD mortality (2000-2010).

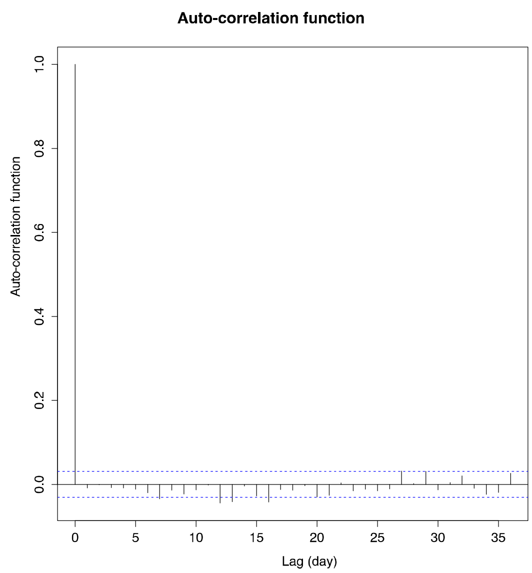
Model validation

The cumulative periodogram test assessed whether the residuals were independent over time. The black diagonal line did not cross the confidence bounds (represented by the blue dotted lines) indicating that the residuals were independent (Supplementary Figure 6**).** Autocorrelation is that observations close in time are more likely to be alike than those separated by time. Because the short-term (day-to-day) association of temperature and NCD-YLL are of interest, it is important to control for season and long-term trends, which can make the short-term associations difficult to detect [1]. The presence of vertical spikes within the confines of the confidence bounds (blue dotted lines) also indicate that autocorrelation was removed in the autocorrelation function plot (Supplementary Figure 7). There was no evidence of autocorrelation after controlling for seasonality and long-term trends in the analysis.

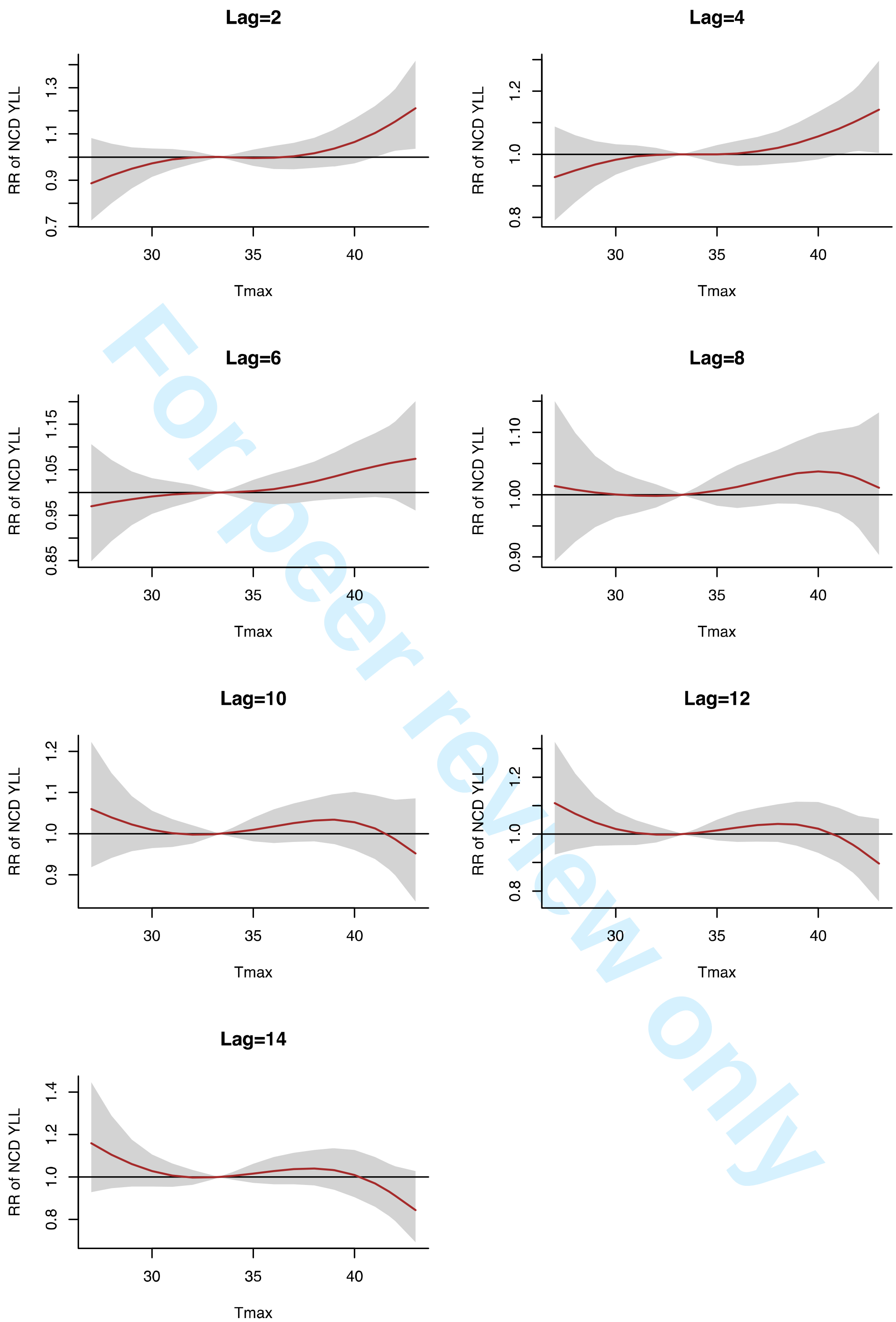
[1] Bhaskaran K, Gasparrini A, Hajat S, Smeeth L, Armstrong B (2013) Time series regression studies in environmental epidemiology. Int J Epidemiol 42:1187–1195.



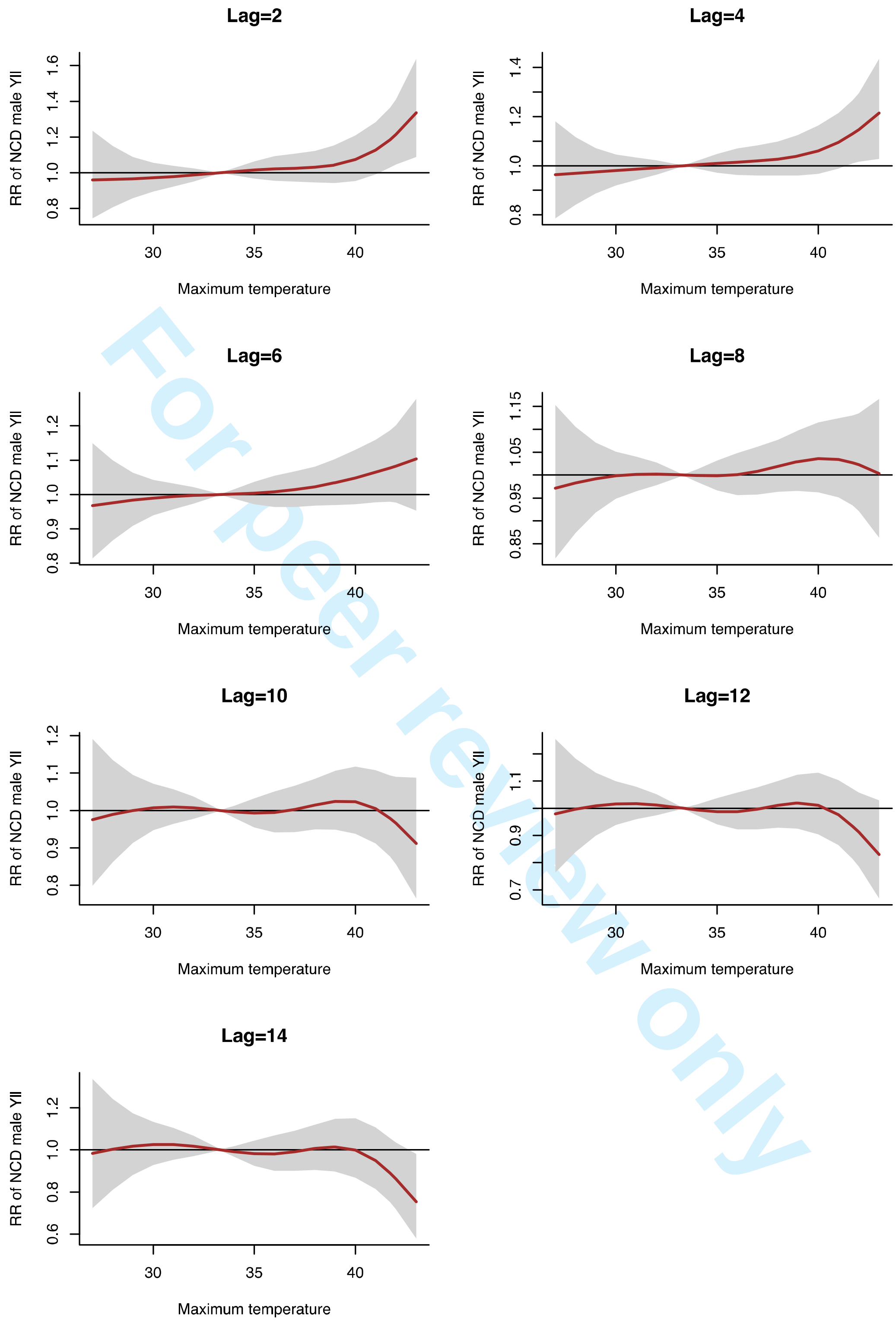
Supplementary Figure 6: Cumulative periodogram test determines the independence of residuals over time. The blue dotted lines are the confidence intervals.



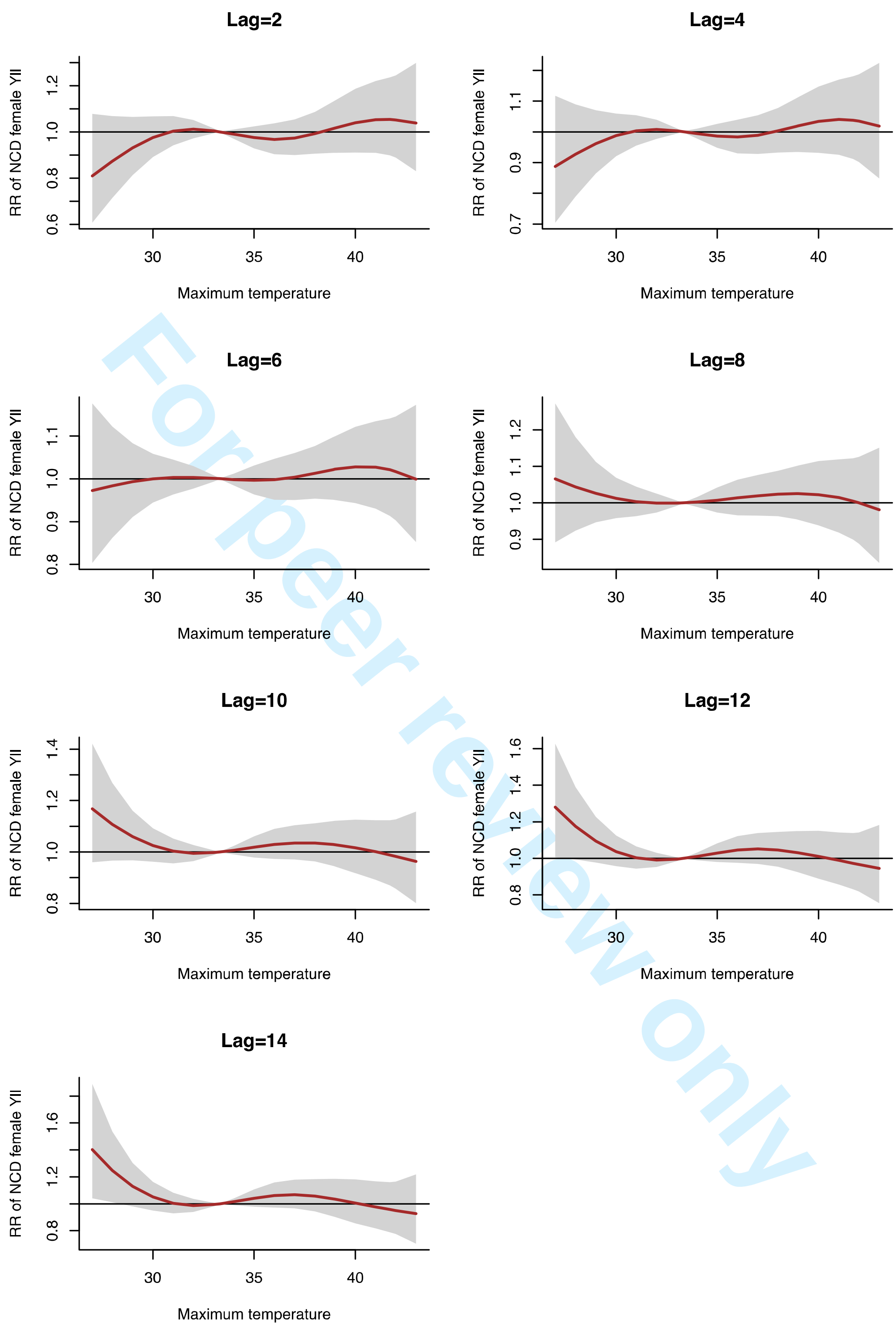
Supplementary Figure 7: Autocorrelation function of the base model. Vertical lines or 'spikes' are placed along individual lag days (*x*-axis). The height of the spike is relative to the magnitude of the autocorrelation function (*y*-axis). Autocorrelation at lag one is always one. Blue dotted lines are the confidence intervals.



Supplementary Figure 8: Plots of the 4-day cumulative relative risk of non-communicable disease years of life lost for all ages stratified by lag days 2-14 (in two day increments).



Supplementary Figure 9: Plots of the 4-day cumulative relative risk of non-communicable disease years of life lost for males stratified by lag days 2-14 (in two day increments).



Supplementary Figure 10: Plots of the 4-day cumulative relative risk of non-communicable disease years of life lost for females stratified by lag days 2-14 (in two day increments).

Supplementary Table 6a: Relative risk (and 95% confidence bounds) of maximum temperature on non-communicable disease all-age years of life lost in Nouna stratified by individual lag days between 2000-2010. Relative risks are presented for; heat effects as 38.9°C, 41.1°C, 41.7°C and 42.8°C with reference to 36.4°C; cold effects as 27.8°C 30°C, 31.1°C and 33.3°C with reference to 36.4°C. Results controlled for long-term trends, season, day of the week, and heaping effect.

	27.8°C (1st percentile)	30°C (5th percentile)	31.1°C (10th percentile)	33.3°C (25th percentile)	38.9°C (75th percentile)	41.4°C (90th percentile)	41.7°C (95th percentile)	42.8°C (99th percentile)
	34 days below 27.8°C	174 days below 30°C	325 days below 31.3°C	912 days below 33.3°C	883 days above 38.9°C	300 days above 41.4°C	189 days above 41.7°C	28 days above 42.8°C
	RR (95% CI)	RR (95% CI)	RR (95% CI)	RR (95% CI)	RR (95% CI)	RR (95% CI)	RR (95% CI)	RR (95% CI)
lag0	0.88 (0.73 to 1.06)	0.96 (0.89 to 1.04)	0.99 (0.94 to 1.04)	1.00 (1.00 to 1.00)	1.03 (0.94 to 1.14)	1.16 (1.02 to 1.31)	1.18 (1.03 to 1.35)	1.27 (1.06 to 1.52)
lag1	0.90 (0.76 to 1.06)	0.97 (0.90 to 1.04)	0.99 (0.94 to 1.04)	1.00 (1.00 to 1.00)	1.03 (0.95 to 1.13)	1.14 (1.01 to 1.28)	1.16 (1.03 to 1.31)	1.23 (1.05 to 1.45)
lag2	0.91 (0.79 to 1.06)	0.97 (0.91 to 1.04)	0.99 (0.95 to 1.03)	1.00 (1.00 to 1.00)	1.03 (0.96 to 1.12)	1.12 (1.01 to 1.25)	1.14 (1.02 to 1.27)	1.20 (1.04 to 1.39)
lag3	0.93 (0.81 to 1.06)	0.98 (0.92 to 1.03)	0.99 (0.96 to 1.03)	1.00 (1.00 to 1.00)	1.03 (0.97 to 1.11)	1.11 (1.01 to 1.22)	1.12 (1.01 to 1.23)	1.17 (1.02 to 1.33)
lag4	0.94 (0.84 to 1.07)	0.98 (0.94 to 1.03)	0.99 (0.96 to 1.03)	1.00 (1.00 to 1.00)	1.03 (0.97 to 1.10)	1.09 (1.00 to 1.19)	1.10 (1.01 to 1.20)	1.13 (1.01 to 1.28)
lag5	0.96 (0.86 to 1.07)	0.99 (0.94 to 1.03)	0.99 (0.97 to 1.03)	1.00 (1.00 to 1.00)	1.03 (0.98 to 1.09)	1.08 (1.00 to 1.16)	1.08 (1.00 to 1.17)	1.10 (0.99 to 1.23)
lag6	0.98 (0.88 to 1.08)	0.99 (0.95 to 1.03)	1.00 (0.97 to 1.02)	1.00 (1.00 to 1.00)	1.03 (0.99 to 1.09)	1.06 (0.99 to 1.14)	1.06 (0.99 to 1.15)	1.07 (0.97 to 1.19)
lag7	0.99 (0.90 to 1.09)	1.00 (0.96 to 1.03)	1.00 (0.97 to 1.02)	1.00 (1.00 to 1.00)	1.03 (0.99 to 1.08)	1.05 (0.98 to 1.12)	1.05 (0.97 to 1.13)	1.04 (0.94 to 1.16)
lag8	1.01 (0.92 to 1.11)	1.00 (0.96 to 1.04)	1.00 (0.97 to 1.03)	1.00 (1.00 to 1.00)	1.03 (0.99 to 1.09)	1.03 (0.96 to 1.11)	1.03 (0.96 to 1.11)	1.01 (0.91 to 1.13)
lag9	1.03 (0.93 to 1.13)	1.00 (0.96 to 1.05)	1.00 (0.97 to 1.03)	1.00 (1.00 to 1.00)	1.03 (0.98 to 1.09)	1.02 (0.94 to 1.10)	1.01 (0.94 to 1.10)	0.99 (0.88 to 1.10)
lag10	1.04 (0.94 to 1.16)	1.01 (0.96 to 1.06)	1.00 (0.97 to 1.03)	1.00 (1.00 to 1.00)	1.03 (0.98 to 1.10)	1.00 (0.92 to 1.09)	1.00 (0.91 to 1.09)	0.96 (0.85 to 1.08)
lag11	1.06 (0.94 to 1.19)	1.01 (0.96 to 1.07)	1.00 (0.97 to 1.04)	1.00 (1.00 to 1.00)	1.03 (0.97 to 1.10)	0.99 (0.90 to 1.08)	0.98 (0.89 to 1.08)	0.93 (0.82 to 1.07)
lag12	1.08 (0.94 to 1.23)	1.02 (0.96 to 1.08)	1.00 (0.96 to 1.05)	1.00 (1.00 to 1.00)	1.03 (0.96 to 1.11)	0.98 (0.88 to 1.08)	0.96 (0.86 to 1.07)	0.91 (0.78 to 1.05)
lag13	1.10 (0.94 to 1.27)	1.02 (0.96 to 1.09)	1.00 (0.96 to 1.05)	1.00 (1.00 to 1.00)	1.03 (0.95 to 1.12)	0.96 (0.86 to 1.08)	0.95 (0.84 to 1.07)	0.88 (0.75 to 1.04)
lag14	1.11 (0.94 to 1.32)	1.03 (0.96 to 1.11)	1.01 (0.95 to 1.06)	1.00 (1.00 to 1.00)	1.03 (0.94 to 1.13)	0.95 (0.84 to 1.08)	0.93 (0.82 to 1.06)	0.86 (0.71 to 1.03)

Supplementary Table 6b: Excess all-age average daily NCD-YLL (and 95% confidence bounds) in Nouna stratified by individual lag days between 2000-2010. Relative risks were used to calculate excess average daily NCD-YLL as follows: (Average daily NCD-YLL of all-age* relative risk) – Average daily NCD-YLL. NCD-YLL are presented for; heat effects as 38.9°C, 41.1°C, 41.7°C and 42.8°C with reference to 36.4°C; cold effects as 27.8°C 30°C, 31.1°C and 33.3°C with reference to 36.4°C. Results controlled for long-term trends, season, day of the week, and heaping effect.

	27.8°C (1st percentile)	30°C (5th percentile)	31.1°C (10th percentile)	33.3°C (25th percentile)	38.9°C (75th percentile)	41.4°C (90th percentile)	41.7°C (95th percentile)	42.8°C (99th percentile)
	34 days below 27.8°C	174 days below 30°C	325 days below 31.3°C	912 days below 33.3°C	883 days above 38.9°C	300 days above 41.4°C	189 days above 41.7°C	28 days above 42.8°C
	YLL (95% CI)	YLL (95% CI)	YLL (95% CI)	YLL (95% CI)	YLL (95% CI)	YLL (95% CI)	YLL (95% CI)	YLL (95% CI)
lag0	-0.53 (-1.22 to 0.30)	-0.16 (-0.50 to 0.20)	-0.05 (-0.29 to 0.20)	0.00 (-0.01 to 0.01)	0.16 (-0.27 to 0.63)	0.71 (0.07 to 1.45)	0.81 (0.13 to 1.59)	1.24 (0.28 to 2.38)
lag1	-0.47 (-1.10 to 0.29)	-0.14 (-0.45 to 0.19)	-0.05 (-0.26 to 0.18)	0.00 (-0.01 to 0.01)	0.16 (-0.23 to 0.58)	0.64 (0.06 to 1.29)	0.72 (0.12 to 1.41)	1.07 (0.23 to 2.07)
lag2	-0.40 (-0.98 to 0.29)	-0.12 (-0.40 to 0.17)	-0.04 (-0.23 to 0.16)	0.00 (0.00 to 0.01)	0.16 (-0.19 to 0.53)	0.57 (0.05 to 1.13)	0.63 (0.09 to 1.24)	0.92 (0.17 to 1.79)
lag3	-0.33 (-0.86 to 0.29)	-0.10 (-0.35 to 0.16)	-0.03 (-0.21 to 0.14)	0.00 (0.00 to 0.00)	0.16 (-0.15 to 0.49)	0.49 (0.04 to 0.99)	0.55 (0.07 to 1.08)	0.77 (0.10 to 1.52)
lag4	-0.25 (-0.75 to 0.30)	-0.08 (-0.30 to 0.15)	-0.03 (-0.18 to 0.13)	0.00 (0.00 to 0.00)	0.16 (-0.12 to 0.45)	0.42 (0.02 to 0.86)	0.46 (0.04 to 0.93)	0.62 (0.03 to 1.28)
lag5	-0.18 (-0.63 to 0.32)	-0.06 (-0.25 to 0.14)	-0.02 (-0.16 to 0.12)	0.00 (0.00 to 0.00)	0.16 (-0.09 to 0.42)	0.35 (-0.01 to 0.74)	0.38 (0.00 to 0.79)	0.47 (-0.05 to 1.06)
lag6	-0.11 (-0.53 to 0.36)	-0.04 (-0.22 to 0.14)	-0.02 (-0.14 to 0.11)	0.00 (0.00 to 0.00)	0.16 (-0.07 to 0.39)	0.28 (-0.05 to 0.64)	0.30 (-0.06 to 0.68)	0.33 (-0.15 to 0.88)
lag7	-0.03 (-0.44 to 0.42)	-0.02 (-0.19 to 0.16)	-0.01 (-0.13 to 0.11)	0.00 (0.00 to 0.00)	0.16 (-0.06 to 0.39)	0.22 (-0.1 to 0.56)	0.21 (-0.12 to 0.58)	0.20 (-0.27 to 0.72)
lag8	0.04 (-0.37 to 0.50)	0.00 (-0.17 to 0.18)	-0.01 (-0.13 to 0.12)	0.00 (0.00 to 0.00)	0.16 (-0.07 to 0.39)	0.15 (-0.17 to 0.49)	0.13 (-0.2 to 0.50)	0.07 (-0.40 to 0.58)
lag9	0.12 (-0.32 to 0.61)	0.02 (-0.16 to 0.21)	0.00 (-0.14 to 0.13)	0.00 (0.00 to 0.00)	0.16 (-0.08 to 0.41)	0.08 (-0.25 to 0.44)	0.06 (-0.30 to 0.44)	-0.06 (-0.54 to 0.47)
lag10	0.20 (-0.29 to 0.74)	0.04 (-0.16 to 0.26)	0.00 (-0.15 to 0.16)	0.00 (-0.01 to 0.00)	0.16 (-0.11 to 0.44)	0.02 (-0.35 to 0.41)	-0.02 (-0.40 to 0.39)	-0.19 (-0.69 to 0.39)
lag11	0.28 (-0.27 to 0.89)	0.06 (-0.17 to 0.31)	0.01 (-0.16 to 0.18)	0.00 (-0.01 to 0.00)	0.16 (-0.15 to 0.48)	-0.05 (-0.44 to 0.38)	-0.10 (-0.51 to 0.36)	-0.31 (-0.85 to 0.31)
lag12	0.36 (-0.26 to 1.07)	0.08 (-0.18 to 0.36)	0.01 (-0.18 to 0.21)	0.00 (-0.01 to 0.00)	0.16 (-0.18 to 0.52)	-0.11 (-0.55 to 0.37)	-0.17 (-0.62 to 0.33)	-0.43 (-1.01 to 0.25)
lag13	0.44 (-0.26 to 1.25)	0.11 (-0.19 to 0.42)	0.02 (-0.20 to 0.24)	0.00 (-0.01 to 0.00)	0.16 (-0.23 to 0.57)	-0.17 (-0.65 to 0.36)	-0.25 (-0.74 to 0.31)	-0.54 (-1.16 to 0.19)
lag14	0.53 (-0.26 to 1.45)	0.13 (-0.21 to 0.49)	0.02 (-0.21 to 0.28)	0.00 (-0.01 to 0.01)	0.15 (-0.27 to 0.62)	-0.24 (-0.75 to 0.35)	-0.32 (-0.85 to 0.29)	-0.65 (-1.31 to 0.14)

Supplementary Table 7a: Relative risk (and 95% confidence bounds) of maximum temperature on non-communicable disease male years of life lost in Nouna stratified by individual lag days between 2000-2010. Relative risks are presented for; heat effects as 38.9°C, 41.1°C, 41.7°C and 42.8°C with reference to 36.4°C; cold effects as 27.8°C 30°C, 31.1°C and 33.3°C with reference to 36.4°C. Results controlled for long-term trends, season, day of the week, and heaping effect.

	27.8 °C (1st percentile)	**30 °C (5th percentile)**	**31.1°C (10th percentile)**	**33.3°C (25th percentile)**	**38.9°C (75th percentile)**	**41.4°C (90th percentile)**	**41.7°C (95th percentile)**	**42.8°C (99th percentile)**
	34 days below 27.8°C	174 days below 30°C	325 days below 31.3°C	912 days below 33.3°C	883 days above 38.9°C	300 days above 41.4°C	189 days above 41.7°C	28 days above 42.8°C
	RR (95% CI)	RR (95% CI)	RR (95% CI)	RR (95% CI)	RR (95% CI)	RR (95% CI)	RR (95% CI)	RR (95% CI)
lag0	0.96 (0.75 to 1.21)	0.96 (0.87 to 1.07)	0.97 (0.90 to 1.04)	1.00 (1.00 to 1.00)	1.05 (0.92 to 1.19)	1.2 (1.02 to 1.42)	1.24 (1.04 to 1.48)	1.43 (1.13 to 1.80)
lag1	0.96 (0.77 to 1.19)	0.97 (0.88 to 1.06)	0.98 (0.92 to 1.04)	1.00 (1.00 to 1.00)	1.04 (0.93 to 1.17)	1.18 (1.02 to 1.37)	1.21 (1.04 to 1.42)	1.37 (1.11 to 1.69)
lag2	0.96 (0.79 to 1.16)	0.97 (0.90 to 1.05)	0.98 (0.93 to 1.04)	1.00 (1.00 to 1.00)	1.04 (0.94 to 1.15)	1.16 (1.01 to 1.33)	1.19 (1.03 to 1.36)	1.31 (1.08 to 1.58)
lag3	0.96 (0.81 to 1.14)	0.98 (0.91 to 1.05)	0.98 (0.93 to 1.03)	1.00 (1.00 to 1.00)	1.04 (0.95 to 1.14)	1.14 (1.01 to 1.28)	1.16 (1.02 to 1.31)	1.25 (1.06 to 1.49)
lag4	0.97 (0.83 to 1.13)	0.98 (0.92 to 1.05)	0.99 (0.94 to 1.03)	1.00 (1.00 to 1.00)	1.04 (0.96 to 1.12)	1.11 (1.00 to 1.24)	1.13 (1.01 to 1.27)	1.20 (1.03 to 1.40)
lag5	0.97 (0.85 to 1.12)	0.99 (0.93 to 1.04)	0.99 (0.95 to 1.03)	1.00 (1.00 to 1.00)	1.04 (0.97 to 1.11)	1.09 (0.99 to 1.20)	1.10 (1.00 to 1.22)	1.15 (0.99 to 1.33)
lag6	0.97 (0.86 to 1.11)	0.99 (0.94 to 1.04)	0.99 (0.96 to 1.03)	1.00 (1.00 to 1.00)	1.03 (0.97 to 1.10)	1.07 (0.98 to 1.17)	1.08 (0.98 to 1.19)	1.10 (0.96 to 1.26)
lag7	0.98 (0.86 to 1.11)	0.99 (0.95 to 1.05)	1.00 (0.96 to 1.03)	1.00 (1.00 to 1.00)	1.03 (0.97 to 1.10)	1.05 (0.96 to 1.15)	1.05 (0.96 to 1.16)	1.05 (0.92 to 1.20)
lag8	0.98 (0.86 to 1.11)	1.00 (0.95 to 1.05)	1.00 (0.97 to 1.04)	1.00 (1.00 to 1.00)	1.03 (0.97 to 1.10)	1.03 (0.94 to 1.13)	1.03 (0.93 to 1.13)	1.01 (0.88 to 1.16)
lag9	0.98 (0.86 to 1.13)	1.00 (0.95 to 1.06)	1.01 (0.97 to 1.05)	1.00 (1.00 to 1.00)	1.03 (0.96 to 1.10)	1.01 (0.92 to 1.11)	1.00 (0.91 to 1.11)	0.96 (0.83 to 1.12)
lag10	0.99 (0.85 to 1.15)	1.01 (0.95 to 1.07)	1.01 (0.97 to 1.06)	1.00 (1.00 to 1.00)	1.02 (0.95 to 1.10)	0.99 (0.89 to 1.10)	0.98 (0.88 to 1.09)	0.92 (0.78 to 1.09)
lag11	0.99 (0.84 to 1.17)	1.01 (0.94 to 1.08)	1.01 (0.96 to 1.07)	1.00 (1.00 to 1.00)	1.02 (0.94 to 1.11)	0.97 (0.87 to 1.09)	0.96 (0.85 to 1.08)	0.88 (0.74 to 1.06)
lag12	0.99 (0.82 to 1.20)	1.02 (0.94 to 1.10)	1.02 (0.96 to 1.08)	1.00 (1.00 to 1.00)	1.02 (0.93 to 1.12)	0.95 (0.84 to 1.09)	0.93 (0.81 to 1.07)	0.85 (0.69 to 1.03)
lag13	1.00 (0.81 to 1.23)	1.02 (0.93 to 1.12)	1.02 (0.96 to 1.09)	1.00 (1.00 to 1.00)	1.02 (0.91 to 1.13)	0.94 (0.81 to 1.08)	0.91 (0.78 to 1.06)	0.81 (0.65 to 1.01)
lag14	1.00 (0.79 to 1.26)	1.03 (0.93 to 1.13)	1.02 (0.95 to 1.10)	1.00 (1.00 to 1.00)	1.01 (0.90 to 1.15)	0.92 (0.78 to 1.08)	0.89 (0.75 to 1.06)	0.78 (0.61 to 0.99)

Supplementary Table 7b: Excess male average daily NCD-YLL (and 95% confidence bounds) in Nouna stratified by individual lag days between 2000-2010. Relative risks were used to calculate excess average daily NCD-YLL as follows: (Average daily NCD-YLL of male * relative risk) – Average daily NCD-YLL. NCD-YLL are presented for; heat effects as 38.9°C, 41.1°C, 41.7°C and 42.8°C with reference to 36.4°C; cold effects as 27.8°C 30°C, 31.1°C and 33.3°C with reference to 36.4°C. Results controlled for long-term trends, season, day of the week, and heaping effect.

	27.8 °C (1st percentile)	**30 °C (5th percentile)**	**31.1°C (10th percentile)**	**33.3°C (25th percentile)**	**38.9°C (75th percentile)**	**41.4°C (90th percentile)**	**41.7°C (95th percentile)**	**42.8°C (99th percentile)**
	34 days below 27.8°C	174 days below 30°C	325 days below 31.3°C	912 days below 33.3°C	883 days above 38.9°C	300 days above 41.4°C	189 days above 41.7°C	28 days above 42.8°C
	YLL (95% CI)	YLL (95% CI)	YLL (95% CI)	YLL (95% CI)	YLL (95% CI)	YLL (95% CI)	YLL (95% CI)	YLL (95% CI)
lag0	-0.11 (-0.59 to 0.51)	-0.09 (-0.31 to 0.16)	-0.07 (-0.23 to 0.11)	0.00 (-0.01 to 0.00)	0.11 (-0.18 to 0.45)	0.49 (0.05 to 1.01)	0.58 (0.11 to 1.15)	1.03 (0.32 to 1.93)
lag1	-0.10 (-0.54 to 0.45)	-0.08 (-0.28 to 0.15)	-0.06 (-0.20 to 0.10)	0.00 (-0.01 to 0.00)	0.11 (-0.16 to 0.41)	0.43 (0.04 to 0.89)	0.51 (0.09 to 1.01)	0.88 (0.26 to 1.65)
lag2	-0.09 (-0.49 to 0.39)	-0.07 (-0.25 to 0.13)	-0.05 (-0.18 to 0.09)	0.00 (0.00 to 0.00)	0.10 (-0.14 to 0.36)	0.38 (0.03 to 0.78)	0.44 (0.07 to 0.87)	0.74 (0.20 to 1.40)
lag3	-0.08 (-0.45 to 0.35)	-0.06 (-0.22 to 0.12)	-0.04 (-0.16 to 0.08)	0.00 (0.00 to 0.00)	0.10 (-0.11 to 0.33)	0.33 (0.02 to 0.68)	0.38 (0.05 to 0.75)	0.61 (0.13 to 1.17)
lag4	-0.08 (-0.41 to 0.31)	-0.05 (-0.19 to 0.11)	-0.03 (-0.13 to 0.08)	0.00 (0.00 to 0.00)	0.09 (-0.10 to 0.29)	0.27 (0.00 to 0.58)	0.31 (0.02 to 0.64)	0.48 (0.06 to 0.96)
lag5	-0.07 (-0.37 to 0.28)	-0.04 (-0.17 to 0.10)	-0.02 (-0.12 to 0.07)	0.00 (0.00 to 0.00)	0.08 (-0.08 to 0.26)	0.22 (-0.02 to 0.49)	0.25 (-0.01 to 0.54)	0.36 (-0.01 to 0.78)
lag6	-0.06 (-0.34 to 0.26)	-0.03 (-0.15 to 0.10)	-0.01 (-0.10 to 0.08)	0.00 (0.00 to 0.00)	0.08 (-0.07 to 0.24)	0.17 (-0.05 to 0.42)	0.19 (-0.05 to 0.45)	0.24 (-0.10 to 0.63)
lag7	-0.05 (-0.33 to 0.26)	-0.01 (-0.13 to 0.11)	0.00 (-0.09 to 0.08)	0.00 (0.00 to 0.00)	0.07 (-0.07 to 0.23)	0.12 (-0.09 to 0.35)	0.12 (-0.1 to 0.37)	0.13 (-0.19 to 0.49)
lag8	-0.05 (-0.33 to 0.27)	0.00 (-0.12 to 0.12)	0.00 (-0.08 to 0.09)	0.00 (0.00 to 0.00)	0.07 (-0.08 to 0.23)	0.07 (-0.14 to 0.30)	0.07 (-0.16 to 0.31)	0.02 (-0.30 to 0.38)
lag9	-0.04 (-0.34 to 0.3)	0.01 (-0.12 to 0.14)	0.01 (-0.08 to 0.11)	0.00 (0.00 to 0.00)	0.06 (-0.10 to 0.24)	0.03 (-0.19 to 0.27)	0.01 (-0.22 to 0.26)	-0.08 (-0.40 to 0.29)
lag10	-0.03 (-0.36 to 0.35)	0.02 (-0.13 to 0.17)	0.02 (-0.08 to 0.13)	0.00 (0.00 to 0.00)	0.06 (-0.12 to 0.25)	-0.02 (-0.25 to 0.24)	-0.05 (-0.30 to 0.23)	-0.18 (-0.52 to 0.21)
lag11	-0.02 (-0.39 to 0.41)	0.03 (-0.14 to 0.20)	0.03 (-0.09 to 0.16)	0.00 (0.00 to 0.00)	0.05 (-0.15 to 0.27)	-0.07 (-0.32 to 0.22)	-0.10 (-0.37 to 0.2)	-0.28 (-0.63 to 0.14)
lag12	-0.02 (-0.42 to 0.47)	0.04 (-0.15 to 0.24)	0.04 (-0.09 to 0.18)	0.00 (0.00 to 0.00)	0.05 (-0.18 to 0.29)	-0.11 (-0.39 to 0.21)	-0.16 (-0.45 to 0.17)	-0.37 (-0.74 to 0.08)
lag13	-0.01 (-0.46 to 0.54)	0.05 (-0.16 to 0.28)	0.05 (-0.10 to 0.21)	0.00 (0.00 to 0.01)	0.04 (-0.21 to 0.32)	-0.15 (-0.46 to 0.19)	-0.21 (-0.52 to 0.15)	-0.46 (-0.84 to 0.03)
lag14	0.00 (-0.50 to 0.62)	0.06 (-0.17 to 0.32)	0.06 (-0.11 to 0.24)	0.00 (0.00 to 0.01)	0.03 (-0.24 to 0.35)	-0.20 (-0.52 to 0.19)	-0.26 (-0.60 to 0.13)	-0.54 (-0.94 to -0.02)

Supplementary Table 8a: Relative risk (and 95% confidence bounds) of maximum temperature on non-communicable disease female years of life lost in Nouna stratified by individual lag days between 2000-2010. Relative risks are presented for; heat effects as 38.9°C, 41.1°C, 41.7°C and 42.8°C with reference to 36.4°C; cold effects as 27.8°C 30°C, 31.1°C and 33.3°C with reference to 36.4°C. Results controlled for long-term trends, season, day of the week, and heaping effect.

	27.8 °C (1st percentile)	**30 °C (5th percentile)**	**31.1°C (10th percentile)**	**33.3°C (25th percentile)**	**38.9°C (75th percentile)**	**41.4°C (90th percentile)**	**41.7°C (95th percentile)**	**42.8°C (99th percentile)**
	34 days below 27.8 °C	174 days below 30 °C	325 days below 31.3°C	912 days below 33.3°C	883 days above 38.9°C	300 days above 41.4°C	189 days above 41.7°C	28 days above 42.8°C
	RR (95% CI)	RR (95% CI)	RR (95% CI)	RR (95% CI)	RR (95% CI)	RR (95% CI)	RR (95% CI)	RR (95% CI)
lag0	0.81 (0.62 to 1.05)	0.96 (0.86 to 1.08)	1.01 (0.93 to 1.09)	1.00 (1.00 to 1.00)	1.01 (0.88 to 1.16)	1.07 (0.89 to 1.29)	1.07 (0.88 to 1.30)	1.06 (0.82 to 1.37)
lag1	0.83 (0.66 to 1.06)	0.97 (0.88 to 1.07)	1.01 (0.94 to 1.08)	1.00 (1.00 to 1.00)	1.01 (0.90 to 1.14)	1.06 (0.90 to 1.26)	1.06 (0.89 to 1.27)	1.05 (0.83 to 1.33)
lag2	0.86 (0.69 to 1.07)	0.98 (0.89 to 1.07)	1.01 (0.95 to 1.07)	1.00 (1.00 to 1.00)	1.01 (0.91 to 1.13)	1.06 (0.91 to 1.23)	1.05 (0.90 to 1.24)	1.04 (0.84 to 1.28)
lag3	0.89 (0.73 to 1.08)	0.98 (0.91 to 1.06)	1.00 (0.95 to 1.06)	1.00 (1.00 to 1.00)	1.02 (0.92 to 1.12)	1.05 (0.91 to 1.20)	1.05 (0.91 to 1.21)	1.03 (0.85 to 1.25)
lag4	0.92 (0.77 to 1.09)	0.99 (0.92 to 1.06)	1.00 (0.96 to 1.05)	1.00 (1.00 to 1.00)	1.02 (0.93 to 1.11)	1.04 (0.92 to 1.18)	1.04 (0.91 to 1.18)	1.02 (0.86 to 1.21)
lag5	0.95 (0.81 to 1.11)	0.99 (0.93 to 1.06)	1.00 (0.96 to 1.05)	1.00 (1.00 to 1.00)	1.02 (0.94 to 1.10)	1.03 (0.92 to 1.15)	1.03 (0.91 to 1.16)	1.01 (0.86 to 1.19)
lag6	0.98 (0.85 to 1.13)	1.00 (0.94 to 1.06)	1.00 (0.96 to 1.04)	1.00 (1.00 to 1.00)	1.02 (0.95 to 1.10)	1.02 (0.92 to 1.14)	1.02 (0.91 to 1.14)	1.00 (0.86 to 1.17)
lag7	1.01 (0.89 to 1.16)	1.01 (0.95 to 1.06)	1.00 (0.97 to 1.04)	1.00 (1.00 to 1.00)	1.02 (0.96 to 1.10)	1.02 (0.92 to 1.13)	1.01 (0.91 to 1.13)	0.99 (0.86 to 1.15)
lag8	1.05 (0.92 to 1.20)	1.01 (0.96 to 1.07)	1.00 (0.96 to 1.04)	1.00 (1.00 to 1.00)	1.03 (0.96 to 1.10)	1.01 (0.91 to 1.12)	1.00 (0.90 to 1.12)	0.98 (0.85 to 1.14)
lag9	1.08 (0.94 to 1.24)	1.02 (0.96 to 1.08)	1.00 (0.96 to 1.04)	1.00 (1.00 to 1.00)	1.03 (0.95 to 1.11)	1.00 (0.90 to 1.12)	1.00 (0.89 to 1.12)	0.98 (0.83 to 1.14)
lag10	1.12 (0.97 to 1.30)	1.02 (0.96 to 1.09)	1.00 (0.96 to 1.05)	1.00 (1.00 to 1.00)	1.03 (0.95 to 1.12)	0.99 (0.88 to 1.12)	0.99 (0.87 to 1.12)	0.97 (0.81 to 1.15)
lag11	1.16 (0.98 to 1.36)	1.03 (0.96 to 1.11)	1.00 (0.95 to 1.05)	1.00 (1.00 to 1.00)	1.03 (0.94 to 1.13)	0.99 (0.86 to 1.13)	0.98 (0.85 to 1.13)	0.96 (0.79 to 1.16)
lag12	1.19 (1.00 to 1.43)	1.04 (0.96 to 1.12)	1.00 (0.94 to 1.06)	1.00 (1.00 to 1.00)	1.03 (0.93 to 1.15)	0.98 (0.84 to 1.14)	0.97 (0.83 to 1.14)	0.95 (0.77 to 1.17)
lag13	1.23 (1.01 to 1.51)	1.04 (0.95 to 1.14)	1.00 (0.94 to 1.07)	1.00 (1.00 to 1.00)	1.03 (0.92 to 1.17)	0.97 (0.82 to 1.15)	0.97 (0.81 to 1.15)	0.94 (0.75 to 1.19)
lag14	1.27 (1.02 to 1.60)	1.05 (0.95 to 1.16)	1.00 (0.93 to 1.08)	1.00 (1.00 to 1.00)	1.04 (0.91 to 1.19)	0.97 (0.80 to 1.16)	0.96 (0.79 to 1.16)	0.93 (0.72 to 1.20)

Supplementary Table 8b: Excess female average daily NCD-YLL (and 95% confidence bounds) in Nouna stratified by individual lag days between 2000-2010. Relative risks were used to calculate excess average daily NCD-YLL as follows: (Average daily NCD-YLL of female * relative risk) – Average daily NCD-YLL. NCD-YLL are presented for; heat effects as 38.9°C, 41.1°C, 41.7°C and 42.8°C with reference to 36.4°C; cold effects as 27.8°C 30°C, 31.1°C and 33.3°C with reference to 36.4°C. Results controlled for long-term trends, season, day of the week, and heaping effect.

	27.8 °C (1st percentile)	**30 °C (5th percentile)**	**31.1°C (10th percentile)**	**33.3°C (25th percentile)**	**38.9°C (75th percentile)**	**41.4°C (90th percentile)**	**41.7°C (95th percentile)**	**42.8°C (99th percentile)**
	34 days below 27.8°C	174 days below 30°C	325 days below 31.3°C	912 days below 33.3°C	883 days above 38.9°C	300 days above 41.4°C	189 days above 41.7°C	28 days above 42.8°C
	YLL (95% CI)	YLL (95% CI)	YLL (95% CI)	YLL (95% CI)	YLL (95% CI)	YLL (95% CI)	YLL (95% CI)	YLL (95% CI)
lag0	-0.41 (-0.80 to 0.11)	-0.08 (-0.29 to 0.16)	0.01 (-0.14 to 0.18)	0.00 (0.00 to 0.01)	0.02 (-0.25 to 0.33)	0.15 (-0.24 to 0.61)	0.15 (-0.25 to 0.63)	0.13 (-0.37 to 0.78)
lag1	-0.35 (-0.72 to 0.13)	-0.06 (-0.26 to 0.15)	0.01 (-0.13 to 0.16)	0.00 (0.00 to 0.01)	0.03 (-0.22 to 0.30)	0.13 (-0.22 to 0.55)	0.13 (-0.23 to 0.56)	0.11 (-0.35 to 0.68)
lag2	-0.29 (-0.64 to 0.15)	-0.05 (-0.23 to 0.14)	0.01 (-0.11 to 0.14)	0.00 (0.00 to 0.00)	0.03 (-0.19 to 0.28)	0.12 (-0.2 to 0.48)	0.11 (-0.21 to 0.50)	0.09 (-0.33 to 0.60)
lag3	-0.23 (-0.56 to 0.17)	-0.04 (-0.20 to 0.13)	0.01 (-0.10 to 0.13)	0.00 (0.00 to 0.00)	0.03 (-0.16 to 0.25)	0.10 (-0.18 to 0.42)	0.10 (-0.20 to 0.43)	0.07 (-0.31 to 0.52)
lag4	-0.17 (-0.48 to 0.20)	-0.03 (-0.17 to 0.13)	0.01 (-0.09 to 0.11)	0.00 (0.00 to 0.00)	0.04 (-0.14 to 0.23)	0.08 (-0.17 to 0.37)	0.08 (-0.19 to 0.38)	0.05 (-0.29 to 0.45)
lag5	-0.10 (-0.39 to 0.23)	-0.01 (-0.14 to 0.12)	0.01 (-0.08 to 0.10)	0.00 (0.00 to 0.00)	0.04 (-0.12 to 0.21)	0.07 (-0.16 to 0.33)	0.06 (-0.18 to 0.33)	0.03 (-0.28 to 0.39)
lag6	-0.04 (-0.31 to 0.28)	0.00 (-0.12 to 0.12)	0.01 (-0.07 to 0.09)	0.00 (0.00 to 0.00)	0.05 (-0.10 to 0.20)	0.05 (-0.16 to 0.29)	0.04 (-0.18 to 0.30)	0.01 (-0.29 to 0.35)
lag7	0.03 (-0.24 to 0.34)	0.01 (-0.10 to 0.13)	0.01 (-0.07 to 0.09)	0.00 (0.00 to 0.00)	0.05 (-0.09 to 0.20)	0.04 (-0.17 to 0.27)	0.03 (-0.19 to 0.27)	-0.01 (-0.30 to 0.32)
lag8	0.10 (-0.17 to 0.41)	0.03 (-0.09 to 0.14)	0.01 (-0.07 to 0.09)	0.00 (0.00 to 0.00)	0.05 (-0.09 to 0.21)	0.02 (-0.19 to 0.25)	0.01 (-0.21 to 0.26)	-0.03 (-0.32 to 0.30)
lag9	0.17 (-0.12 to 0.51)	0.04 (-0.08 to 0.17)	0.00 (-0.08 to 0.09)	0.00 (0.00 to 0.00)	0.06 (-0.10 to 0.23)	0.00 (-0.22 to 0.25)	-0.01 (-0.24 to 0.25)	-0.05 (-0.35 to 0.30)
lag10	0.25 (-0.07 to 0.62)	0.05 (-0.08 to 0.19)	0.00 (-0.09 to 0.10)	0.00 (0.00 to 0.00)	0.06 (-0.11 to 0.25)	-0.01 (-0.25 to 0.26)	-0.02 (-0.27 to 0.26)	-0.07 (-0.39 to 0.31)
lag11	0.33 (-0.04 to 0.75)	0.07 (-0.08 to 0.22)	0.00 (-0.10 to 0.11)	0.00 (0.00 to 0.00)	0.06 (-0.13 to 0.28)	-0.03 (-0.29 to 0.27)	-0.04 (-0.31 to 0.27)	-0.09 (-0.44 to 0.33)
lag12	0.41 (-0.01 to 0.90)	0.08 (-0.09 to 0.26)	0.00 (-0.12 to 0.13)	0.00 (0.00 to 0.00)	0.07 (-0.15 to 0.31)	-0.04 (-0.33 to 0.29)	-0.06 (-0.35 to 0.29)	-0.11 (-0.48 to 0.36)
lag13	0.49 (0.02 to 1.07)	0.09 (-0.10 to 0.30)	0.00 (-0.13 to 0.14)	0.00 (-0.01 to 0.00)	0.07 (-0.17 to 0.35)	-0.06 (-0.37 to 0.31)	-0.07 (-0.40 to 0.31)	-0.13 (-0.54 to 0.39)
lag14	0.58 (0.04 to 1.25)	0.11 (-0.11 to 0.34)	0.00 (-0.15 to 0.16)	0.00 (-0.01 to 0.00)	0.08 (-0.20 to 0.39)	-0.07 (-0.42 to 0.34)	-0.09 (-0.44 to 0.34)	-0.14 (-0.59 to 0.43)

Effect estimates withstood changes to model parameters.

Supplementary Table 9: Cumulative relative risk (and 95% confidence bounds) of maximum temperature on NCD years of life lost in Nouna between 2000-2010 at 41.7°C with reference to 36.4°C stratified by variations in model parameters. Results controlled for long-term trends, season, day of the week, and heaping effect. df=degrees of freedom.

	Lag structure	RR (95% CI)
Knots for exposure-response: 10th, 50th, and 90th (Base model)	4 day cumulative	2.08 (1.08 to 4.01)
Knots for exposure-response: 10th, 75th, and 90th	4 day cumulative	2.10 (1.07 to 4.13)
Knots for exposure-response: 10th, 25th, 75th and 90th	4 day cumulative	2.11 (1.07 to 4.15)
Cubic B-spline for exposure-response	4 day cumulative	2.11 (0.96 to 4.66)
Df for exposure-response:3df, and lag-response: 3df	4 day cumulative	2.14 (1.10 to 4.15)
Df for lag-response: 5	4 day cumulative	1.98 (1.02 to 3.87)
Df/year for seasonal control: 5	4 day cumulative	1.47 (0.82 to 2.64)
Df/year for seasonal control: 6	4 day cumulative	1.61 (0.87 to 3.01)
Df/year for seasonal control: 7	4 day cumulative	2.00 (1.06 to 3.80)
Df/year for seasonal control: 10	4 day cumulative	2.14 (1.09 to 4.22)
Log YLL with gaussian family	4 day cumulative	1.82 (0.96 to 3.45)
Extending lag period: 14 days lag	14 day cumulative	1.98 (0.66 to 5.91)
Extending lag period: 28 days lag	28 day cumulative	0.67 (0.11 to 4.24)

The model applying a natural cubic spline with knots placed at the 10th, 50th and 90th percentile for the exposure-response relationship, and 2 degrees of freedom with equal knot placement for the lag-response relationship along a logarithmic scale presented the lowest Quasi Akaike Information Criterion (QAIC). This was therefore selected as the final model.

Supplementary Table 10: Quasi Akaike Information Criterion (QAIC) values used for selecting the optimal model. NS=natural cubic spline, BS=cubic B-spline, tmax=maximum temperature, df=degrees of freedom.

Model	QAIC
NS knots placed at 10, 50, 90th percentile for tmax, 2df lag	4320.82
NS knots placed at 10, 50, 90th percentile for tmax, 3df lag	4324.96
NS knots placed at 10, 50, 90th percentile for tmax, 5df lag	4333.91
NS knots placed at 10, 25, 75, 90th percentile for tmax, 2df lag	4323.75
NS knots placed at 10, 75, 90th percentile for tmax, 2df lag	4320.91
NS equal knots for exposure-response, 2df tmax, 2df lag	4326.68
NS equal knots for exposure-response, 4df tmax, 2df lag	4331.27
NS equal knots for exposure-response, 3df tmax, 2df lag	4328.83
NS equal knots for eposure-response, 3df tmax, 3df lag	4332.39
BS knots placed at 10, 50, 90th percentile for tmax, 4df for lag (2df for lag were too few)	4340.54

STROBE Statement—Checklist of items that should be included in reports of ***cohort studies***

	Item No	Recommendation
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract [within title page and abstract under 'design']
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found [see abstract under 'results']
Introduction		
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported [pg 4]
Objectives	3	State specific objectives, including any prespecified hypotheses [pg 5]
Methods		
Study design	4	Present key elements of study design early in the paper [pg 5-8]
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection [pg 5-7]
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up [pg 5-7]
		(*b*) For matched studies, give matching criteria and number of exposed and unexposed [n/a]
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable [pg 5-8]
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group [pg 5-8]
Bias	9	Describe any efforts to address potential sources of bias [n/a]
Study size	10	Explain how the study size was arrived at [n/a]
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why [pg 8-9]
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding [for all statistical methods *a-e*: pg 7-9]
		(*b*) Describe any methods used to examine subgroups and interactions
		(*c*) Explain how missing data were addressed
		(*d*) If applicable, explain how loss to follow-up was addressed
		(*e*) Describe any sensitivity analyses
Results		
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed [n/a]
		(b) Give reasons for non-participation at each stage
		(c) Consider use of a flow diagram
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders [for all descriptive data *a-c*: pg 9, Table 2]
		(b) Indicate number of participants with missing data for each variable of interest
		(c) Summarise follow-up time (eg, average and total amount)
Outcome data	15*	Report numbers of outcome events or summary measures over time [pg 9-11, Table 1,2]
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and

		their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included [all main results *a-c*: pg 9-11, Tables 3-4, Figures 1-3]
		(*b*) Report category boundaries when continuous variables were categorized
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses [pg 11]
Discussion		
Key results	18	Summarise key results with reference to study objectives [pg 11]
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias [pg 14]
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence [pg 11-13]
Generalisability	21	Discuss the generalisability (external validity) of the study results [pg 14]
Other information		
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based [pg 15]

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at http://www.strobe-statement.org.

BMJ Open

Excess burden of non-communicable disease years of life lost from heat in rural Burkina Faso: a time-series analysis of the years 2000-2010

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2017-018068.R1
Article Type:	Research
Date Submitted by the Author:	15-Sep-2017

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Primary Subject Heading:	Epidemiology
Secondary Subject Heading:	Global health, Public health
Keywords:	Heat, Year of life lost, Non-communicable disease, Sub-Saharan Africa, Time-series

Excess burden of non-communicable disease years of life lost from heat in rural Burkina Faso: a time-series analysis of the years 2000-2010

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Abstract

Objectives

Investigate the association of heat exposure on years of life lost (YLL) from non-communicable diseases (NCD) in Nouna, Burkina Faso between 2000-2010.

Design

Daily time-series regression analysis using distributed lag non-linear models, assuming a quasi-Poisson distribution of YLL.

Setting

Nouna Health and Demographic Surveillance System, Kossi Province, Rural Burkina Faso.

Participants

18,367 NCD-YLL corresponding to 790 NCD deaths recorded in the Nouna HDSS register over 11 years.

Main outcome measure

Excess mean daily NCD-YLL were generated from the relative risk of maximum daily temperature on NCD-YLL, including effects delayed up to 14 days.

Results

Daily average NCD-YLL were 4.6, 2.4 and 2.1 person-years for all-ages, males and females, respectively. Moderate 4-day cumulative rise in maximum temperature from 36.4°C (50th percentile) to 41.4°C (90th percentile) resulted in 4.44 (95% CI 0.24 to 12.28) excess daily NCD-YLL for all-ages, rising to 7.39 (0.32 to 24.62) at extreme temperature (42.8°C; 99th percentile). The strongest health effects manifested on the day of heat exposure (lag 0), where 0.81 (0.13 to 1.59) excess mean NCD-YLL occurred daily at 41.7°C compared to 36.4°C, diminishing in statistical significance after 4 days. At lag 0, daily excess mean NCD-YLL were higher for males 0.58 (0.11 to 1.15) compared to females 0.15 (-0.25 to 9.63) at 41.7°C versus 36.4°C.

Conclusion

Premature death from NCD was elevated significantly with moderate and extreme heat exposure. These findings have important implications for developing adaptation and mitigation strategies to reduce ambient heat exposure and preventive measures for limiting NCD in Africa.

Key words: temperature, heat, years of life lost, non-communicable disease, Africa, time-series.

Strengths and limitations of this study

- This study investigated the relationship between two defining public health issues affecting Sub-Saharan Africa; increasing ambient heat from climate change and the rising prevalence of non-communicable disease
- Eleven years of high-quality health and demographic data from rural Africa was exploited for analysis
- Only premature death was quantified as the outcome because long-term morbidity data were unavailable
- Temperature data from a weather station located 53 km from the study location was used as a proxy for individual level temperature exposure.

Introduction

As the global average temperature rises, epidemiological evidence on the temperature-health association in neglected African populations is needed to develop appropriate interventions. Surface temperature over West Africa and the Sahel increased by 0.5-0.8°C between 1970 and 2010, and at a faster pace in the most recent 20 years [1]. Analysis of longitudinal data from 12 Health and Demographic Surveillance Sites (HDSS), which includes the Nouna HDSS in Burkina Faso, forecasts that the mean temperature in Africa will exceed the 1900-2000 decadal average by 2100 under all climate change scenarios [2]. In a study applying six climate model-future scenarios across six HDSS sites, the most conservative combination, rapid economic growth and balanced energy sources resulted in a 0.5-1°C temperature increase by 2100, whereas most combinations projected a 2-3°C temperature rise in the same period [2]. Prolonged exposure to high ambient temperature in the subsistence farming community of Nouna, and low adaptive capacity makes this community particularly vulnerable to the effects of temperature increase.

Non-communicable disease (NCD) cause substantial economic drain to society by adversely affecting four pillars of economic growth; labour supply, productivity, investments and education. Projections from 2006 indicated that if no action was taken to reduce the risk of NCD in 23 low-and-middle income countries, US$83 billion would be lost over the subsequent decade to the impact of heart disease, stroke and diabetes [3]. As life expectancy increases in Burkina Faso, people will have more time to develop chronic and degenerative disorders; NCD will therefore contribute increasingly to population mortality. In 2014, NCD accounted for 32% of all deaths in Burkina Faso. The main contributors were cardiovascular disease, cancer, chronic respiratory disease and diabetes [4]. In 2011, Friel *et al.* presented a review exposing the link between climate change and a wide range of NCD, and argued that more frequent and intense heat extremes could exacerbate cardiovascular and respiratory health outcomes [5].

Previous studies have explored the impact of extreme events such as heatwaves or cold waves [6,7] on health, which are anticipated to increase in frequency and magnitude with climate change [8]. A recent multicity study, however, found that milder non-optimal temperature rather than extreme temperature was responsible for most of the temperature-related mortality burden (defined as below the 2.5th and above the 97.5th percentile) [9]. Unfortunately, no African studies were included by Gasparrini *et al.* [9]. Heat (and cold) waves are defined by magnitude and duration; for example, two or more consecutive days exceeding the 98-99th (or 1-2nd) percentile of the temperature range. Excess risks are a comparison of heatwave periods with non-heatwaves periods in previous years. Our study investigates the health risks of moderate to extreme heat, where extreme temperature is defined as below the 5th and above the 95th percentiles of maximum temperature.

Epidemiological studies on the temperature-health association in African populations have primarily measured daily deaths as the outcome [10,11]. Rather than the number of deaths, we used years of life lost (YLL), a global burden of disease (GBD) outcome metric for ascertaining premature death. YLL is an aggregate of life expectancy and death counts that gives the absolute value of years of life lost from a certain exposure, rather than a relative risk. In the only previous study set in Africa investigating the temperature-YLL association, Egondi *et al.* found no heat effects on *all-cause* YLL in the East African highlands of Nairobi, Kenya. A reduction in temperature (21°C compared with 26°C), however, resulted in 27.4 excess all-cause YLL per day (95% CI 2.7 to 52.0) [12]. The current article addresses Africa's dual challenge of coping with rising temperatures from climate change and increasing prevalence of NCD. The association between temperature and other health outcomes in Nouna, including infectious disease will be the subject of future work. The paucity of population-based studies set in African focused on the impact of temperature on NCD health outcomes suggests further studies are required. Our study addresses this research gap by investigating the impact of 11 years of heat exposure on YLL from NCD in the Nouna HDSS.

Methods

Data collection

Health outcome data were obtained from the HDSS, Centre de Recherche en Santé de Nouna, Burkina Faso [13]. All registered deaths between 1 January 2000 to 31 December 2010 were included. Vital statistics for each resident included a unique identifying number (ID), date of birth, date of immigration into the HDSS, date of death, date of emigration from the HDSS and gender. Raw mortality data comprised a unique ID number for each death event, date of birth, date of death, sex, cause of death coded as an International Classification of Disease (ICD10) code, and an accompanying cause of death in French. Cause of death was established by verbal autopsy [14]. Age of death was calculated as the difference between the date of death and birth. We applied the GBD cause-specific categories and ICD10 codes to define NCD as an aggregate of: malignant neoplasms (C00-C97), other neoplasms (D00-D48), diabetes mellitus (E10-E14), endocrine disorders (D55-D64; minus-D64.9, D65-D89, E03-E07, E15-16, E20-E34, E65-E88), neuropsychiatric conditions (F01-F99, G06-G98), sense organ diseases (H00-H61, H68-H93), cardiovascular diseases (I00-I99), respiratory diseases (J30-J98), digestive diseases (K00-K92), genitourinary diseases (N00-N64, N75-N98), skin diseases (L00-L98), musculoskeletal diseases (M00-M99) and congenital anomalies (Q00-Q99) [15].

Computation of daily years of life lost

Different resolutions of life tables can be used to calculate YLL i.e. global, country-level or local life expectancy depending on the purpose of the study. In 1990, the GBD approach calculated YLL relative to the life expectancy of Japanese men and women, the highest for any societal group [16]. Weights for age and time preference can additionally be applied to reduce the contribution of death before adulthood [17]. For the GBD 2010 study, a reference standard of 86 years at birth was used for both males and females and YLL were calculated using a life table based on the lowest observed mortality in each age group in countries with more than five million inhabitants [18]. This study used local rather than global life tables, as done in similar studies [19-21] to present realistic potential losses or gains in life years for the Nouna population grounded in real data (rather than modelled data), which is more meaningful for local decision makers. The cause of death and demographic data from the Nouna HDSS were used to build life tables for the Nouna population. The use of global life expectancy would likely produce very large YLL for populations with low life expectancy such as in Burkina Faso. Furthermore, global life expectancy is likely to be more useful when comparing YLL between two countries, which was not the aim of this study.

We used the Nouna HDSS vital events and mortality data from 2000-2010 to produce age-specific death rates. We generated gender-specific life tables to account for varying life expectancies between men and women (details in **Supplementary File**). Mean additional survival time, averaged between 2000-2010 was calculated for each age band to account for the changing population profile over this time. Abridged life tables were created in five-year increments, producing stable life expectancy estimates for a relatively small population (approximately 90,000 inhabitants in 2012 [10]). The 0-1, and 1-5 age groups were, however, separated. Combining these ages would mask the lower remaining life expectancy for the 0-1 age relative to the 1-5 age group, a consequence of high infant mortality. For each NCD death, YLL were calculated by matching age and sex with the relevant life table. Daily YLL were an aggregate of individual YLL on the respective day calculated as:

a) individual YLL at time of death:

$$YLL_{individual\ (i)} = LE_{remaining} - Age_{death} \quad [1]$$

b) total daily YLL:

$$YLL_{daily} = \sum_{i=1}^{n} YLL_i \quad [2]$$

where:

i is the ith individual

$LE_{remaining}$ is the conditional life expectancy

Age_{death} is the age at death

n is the number of deaths occurring on a given day.

We stratified NCD-YLL by sex to assess if gender differences existed.

Temperature data

Because temperature data for Nouna were not sufficiently complete for analysis, we obtained hourly mean (t-mean), maximum (t-max) and minimum (t-min) temperature data from the National Climatic Data Centre for the Dédougou weather station (12.4° N, 3.4° W) from 1 January 2000 to 31 December 2010 (4071 days). Pearson's correlation analysis was performed to compare maximum temperature between a local Nouna weather station (coordinates 12.7° N, 3.9° W) and the Dédougou weather station (located 53 km from Nouna). Over the study period of 4071 days, 2432 days (59%) of maximum temperature from Nouna were available for comparison. The very strong correlation coefficient of 0.93 (95% CI 0.92 to 0.94), p-value < 2.2e-16 indicated there was little variability between the two sites, validating our use of Dédougou maximum temperature for Nouna. Hourly Dédougou data were averaged to give a daily temperature. The raw time-series consisted of 25% missing t-mean, 14% t-max and 17% t-min. We created an imputation algorithm by averaging 15 consecutive days of temperature either side of a missing temperature value to create a 30-day moving average. The Time Indexes and Time Indexed Series (tis) package *v.*1.30 was applied in *R* software to impute missing temperature values.

Statistical modelling

We applied time-series quasi-Poisson regression analysis, using a distributed lag non-linear model (DLNM) to investigate the association between maximum daily temperature and NCD-YLL.

A natural cubic spline with eight degrees of freedom per year was applied to control for season and long-term time-trends. A heaping effect was found in the raw data (**Supplementary Table 5 and Supplementary Figure 1-2**), where deaths of an unknown date were assigned to the 9th day of the corresponding month. An indicator variable was added to mark and control for heaping of deaths and day of the week. The DLNM captured the immediate and delayed effects of temperature (lags) on health, known as the lag-response association as single lag days, or as it cumulates over time. The exposure-response curve was modelled with a natural cubic spline with knots placed at the 10th, 50th and 90th percentiles. The lag-response was modelled with a natural cubic spline of two degrees of freedom, resulting in default knot placement equally along a logarithmic scale. The model equation was:

$$E(Y_t) = \beta_o + s(T, timedf) + f(X_{tmax}, lagdf, vardf) + DOW + \ HP$$
$$E(Y_t) \sim quasi - Poisson \qquad [3]$$

where:

$E(Y_t)$ is the daily YLL

β_o is the y intercept

$s(T, timedf)$ is the smooth function of time with specified df $timedf$

$f(X_{tmax}, lagdf, vardf)$ is the cross-basis function of t-max and the associated lag dimension with *vardf* and *lagdf* degrees of freedom respectively. DOW accounts for day of week and HP for the heaping effect.

From the RR, absolute values of excess mean daily NCD-YLL were calculated as:

$$(Average\ daily\ NCD - YLL \times RR) - Average\ daily\ NCD - YLL \tag{4}$$

All effect estimates were presented against the median t-max of 36.4°C either as overall 4-day and 14-day cumulative RRs (and corresponding excess mean daily NCD-YLL), or single-day lags extending to 14 days.

Several sensitivity analyses were conducted to test the robustness of altering model choices including; specifying alternative knot positions for exposure-response at the 10th, 75th and 90th, and 10th, 25th, 75th and 90th percentiles, extending degrees of freedom (df) for the lag-response between 2 to 6df, manipulating control for season and time-trend ranging between 5-10df, logarithm transformation of YLL and applying a Gaussian distribution, and extending the lag period to 28 days to assess if temperature exposure triggered NCD deaths on a longer time scale. Quasi-Akaiki information criteria (QAIC) values were calculated to guide model selection. All statistical analyses were conducted using *R* software *v*.3.2.2. Distributed lag non-linear models were fitted using the DLNM package *v*.2.2.3.

Results

The 790 NCD deaths correspond to 18,367 YLL over the study period. Cardiovascular diseases were the largest contributor to NCD-YLL, accounting for 9095 or 50% of all NCD-YLL. Digestive disorders, malignant neoplasms, genitourinary and neuropsychiatric conditions also contributed substantially towards NCD-YLL. Interestingly, endocrine disorders (including diabetes mellitus) formed a very small proportion (1%) of all NCD-YLL **(Table 1)**. **Table 2** shows that maximum mortality peaked at five deaths per day, corresponding to 154 daily NCD-YLL. Daily mean NCD-YLL were 4.6, 2.4 and 2.1 person-years for all-ages, males and females, respectively. Maximum daily temperature was 36.4°C at the 50th percentile, peaking at 43.9°C in the study period.

Figure 1 shows 3D graphs of the RR of NCD-YLL at a range of maximum temperature and lag values, centred at the reference temperature of 36.4°C (all RRs and excess mean daily NCD-YLL in the results are given as a comparison to this reference temperature). All-age (panel A) and male (panel B) plots showed a strong surge in the RR with high temperature close to the time of heat exposure. Males presented no noticeable effect with colder temperature. In contrast, women (panel C) and the all-age group showed more prominent health effects with cooler temperatures, which increased at longer lags. The lag structure of 0-4 days was used to identify immediate health effects [22], which were expanded to 14 days to verify if the effects persisted or were concentrated in earlier days. Single day lagged effects from 0-14 days were also considered to identify mortality displacement trends with longer lags. The main results were the 4- and 14-day cumulative (**Table 3a and Figure 2)** and single-day lagged RR of NCD-YLL **(Table 4a and Figure 3)**, from which daily excess mean NCD-YLL was calculated **(Tables 3b and 4b)**.

Heat effects on NCD-YLL were felt strongly in Nouna above the 50th percentile. Over four cumulative days, exposure to moderate temperature (90th percentile at 41.3°C) was associated with a statistically significant increase of excess mean daily NCD-YLL by 4.44 (0.24 to 12.28) for all-ages, 3.73 (0.33 to 11.39) for males, but remained statistically insignificant for females 0.43 (-1.08 to 4.16). In comparison to the 90th percentile, excess mean daily NCD-YLL increased slightly at 95th percentile (41.7°C) for all ages and males, but not females (**Table 3b**). Extreme heat exposure (99th percentile) over four days increased excess daily mean NCD-YLL for all-ages to 7.39 (0.32 to 24.62) and 8.65 (1.07 to 32.73) for males in contrast to the minimal increase for females; 0.12 (-1.48 to 5.86). Extending the cumulative effect to 14 days also resulted in elevated excess daily mean NCD-YLL, but wider 95% confidence bounds rendered the effect estimates for all three groups statistically insignificance.

Across 14 individual lag days **(Figure 3)**, the largest heat effects were felt immediately (at lag 0); excess daily mean NCD-YLL were 0.81 (0.13 to 1.59) for all-ages, 0.58 (0.11 to 1.15) for males, and 0.15 (-0.25 to 0.63) for females at 41.7°C (**Table 4b**). Heat effects tapered after lag 0, but remained statistically significant to lag 4 at 41.7°C for all-ages and males. For the 95th percentile, a gradual reduction in excess daily mean NCD-YLL (statistically insignificant) was observed up to 8-10 lag days for all-ages, males and females with no subsequent increase.

A reduction in temperature to 30°C **(Figure 3)**, resulted in a slightly protective effect at shorter lags (0-5), but after 14 days the excess daily NCD-YLL were slightly elevated for all subgroup; 0.13 (-0.21 to 0.49) for all-ages; 0.06 (-0.17 to 0.32) for males; and 0.11 (-0.11 to 0.34) for females **(Table 4b)**. Females were the only group to present a statistically significant increase in mean daily NCD-YLL with extreme cold (1st percentile) at lag 13 and 14 **(Supplementary Table 8b)**.

Excess mean daily NCD-YLL were elevated with heat exposure for the 65+ age group, however, the low sample size produced very large confidence bounds (i.e. 0.14 (-0.89 to 86.35) at 38.9°C versus 36.4°C.

Several sensitivity analyses were conducted to validate model selection, including generating QAIC, where lower QAIC indicate better model fit (**Supplementary Tables 9 and 10**). Because increasing the df produces lower QAIC values, we used prior examples to achieve a balance in controlling for season and long-term trend to 8 df per year [9]. Applying 7 df per year, as used in other studies did not greatly affect the risk estimates [21,23]. The natural cubic spline produced lower QAIC in comparison to the more flexible cubic B-spline. Varying knot position and numbers for the exposure-response relationship also did not vary effect estimates. Using 3 df for the lag-response relationship produced the classic reversed J curve expected for heat effects, however, 2 df generated lower QAICs indicating better model fit. There was no evidence of autocorrelation (**Supplementary Figures 6-7**).

Discussion

A central finding of this study was that excess premature deaths from NCD increased with moderate and extreme heat in rural Sub Saharan Africa. The magnitude of health effects worsened with heat intensity. The largest increase in excess premature mortality from NCD occurred rapidly, on the day of heat exposure (lag 0), and diminished in statistical significance after 4 days. The effects of heat on NCD-YLL were greater in males in comparison to females.

In Nairobi, Kenya, increase in temperature over 14 days from 26°C to 30°C resulted in 3.3 (95% CI -19.7 to 26.4) YLL per day, but from *all causes* [12]. Similarly, a change in temperature from the 50th to 75th percentile (36.4 to 38.9°C) in Nouna resulted in 3.01 (-0.84 to 10.82) excess daily *NCD-YLL* over 14 days. Unlike Nouna, the temperature in Nairobi does not typically exceed 40°C. As the only existing African study presenting outcomes as YLL, the comparison presented here indicated ~3 daily YLL in Nouna and Nairobi with a similar temperature increase. Unfortunately, a direct contrast of results between these two African studies is limited because YLL in Nouna were from NCD only, but from all causes of death in Nairobi.

In Australia and China heat exposure increased the YLL from cardiovascular disease. A total of 45 years were lost daily from cardiovascular disease (95% CI 22 to 67 years) in Brisbane, Australia, at a mean temperature of 32°C versus 24°C [19]. In Guangzhou, China (lag 0-14), a change in mean temperature from the 75th (28°C) to 99th percentile (32°C) resulted in 4.81 (-2.25 to 11.88) daily YLL from cardiovascular disease [21]. Cardiovascular disease contributed to 50% of YLL in Nouna. Although subgroup analysis of NCD was limited by sample size in Nouna, the magnitude of effects was closer to Guangzhou than Brisbane; 4.07 (-2.73 to 35.66) and 7.39 (0.32 to 24.62) mean daily YLLs were found from *all NCD* at lag 0-14 and lag 0-4 respectively at the 50th versus 99th percentile. Heat can exacerbate cardiovascular strain, through increased cardiac output, blood viscosity and coagulation, attenuated vasoconstriction, and cerebral perfusion pressure [24]. Our findings agree with those from Guangzhou and Brisbane [19,21], where heat effects occurred rapidly at lag 0, lasting a maximum of 4 days. In contrast to Brisbane, Nouna and Guangzhou exhibited fewer YLL for a similar age and temperature shift. All sites used regional or local life tables to calculate YLL rather than global life tables, so the elevated YLL in Brisbane are unlikely to be attributable to lower life expectancy in Nouna compared to Brisbane. Unlike Brisbane, the predominant cause of death in Nouna is still infectious disease; most days in the Nouna time series exhibited no YLL from NCD. Temperature-related premature death from NCD could increase in Nouna as the epidemiological transition progresses, increasing the proportion of deaths attributable to NCD in the future.

Daily respiratory YLL increased by 2.81 (-1.54 to 7.16) in Guangzhou at 28°C versus 32°C [21] where infectious and chronic respiratory deaths were grouped together as ICD-10 J00-99. In this analysis, however, chronic respiratory YLL (ICD-10 J30-98) only contributed to 2% of total NCD-YLL in Nouna. The separation of chronic and acute respiratory outcomes maybe relevant for comparing findings from different studies and understanding the causal mechanisms. Digestive, renal and neuropsychiatric causes contributed substantially to overall NCD-YLL in Nouna. Heat is known to trigger renal [25] and mental health-related deaths [26], however, the link to chronic digestive causes requires further investigation.

Although excess NCD-YLL for women was elevated with heat exposure, male NCD-YLL were affected by a greater magnitude at lag 0-2. One explanation is that men working outdoors might have higher exposed to ambient heat. Occupational stress has been associated with excess risk of NCD morbidity including psychological distress[27] and kidney disease [28]. These results are somewhat unexpected considering that women in Nouna are exposed to extra heat from cooking and carrying wood/water for 2-3 hours daily. Women might die prematurely from other causes such as childbirth, leaving men to be more affected by diseases associated with longevity such as cardiovascular disease, however, further investigation of gender differences is warranted.

Contrary to findings across 14 European cities [29], we found no evidence of harvesting effects with heat; gradual reduction in YLL across lag days ensuing the initial surge were not associated with significant subsequent negative associations or a rise again in risk estimates for any subgroups [22]. The public health relevance of our findings is therefore enhanced, as premature NCD mortality is not merely the advancement of death in frail individuals with pre-existing chronic conditions.

This study has several strengths. An 11-year time series of reliable, high-quality data from a rural African setting was used to quantify the burden of temperature on NCD-YLL. Variables such as the date, age and cause of death were subject to quality checks and continuous improvements at International Network for the Demographic Evaluation of Populations and Their Health (INDEPTH) sites including Nouna. These processes enabled one of the best quality and most extensive longituidnal health datasets in Africa and Asia to be used for this study. The DLNM accounted for non-linearity and lagged effects. In place of relative risks which would have been obtained had only death counts been used, combining life expectancy and death counts gave an absolute value for YLL from NCD, which is relevant for policy making [30]. Despite the low number of NCD deaths, significant effects of heat on premature mortality were detected, indicating that the effects were strong. The results in the final model were robust and withstood variations of model parameters. Rather than focusing only on anomalous weather events such as heatwaves, one of the longest time series available in rural Africa was exploited to highlight that excess premature deaths from NCD does not only occur during extreme heat, but with moderate heat.

Some limitations are also noted. Caution should be exercised in generalising these findings to all rural African settings. Temperature data were obtained from the nearest location with a similar temperature profile to Nouna. Air pollution data were unavailable to assess potential confounding effects of the exposure-response relationship. The lower resolution and distribution of weather data in Burkina Faso compared to Organisation for Economic Co-operation and Development (OECD) countries can make it challenging to obtain suitable weather data in Burkina Faso. Public health scientists ought to address this challenge by extending research beyond where the data are best, to where problems are the greatest and research/solutions most needed. It is likely that cancer or mental disorders were under-reported as sophisticated questionnaires and tests are needed to establish these causes. In 2004, the World Health Organization (WHO) estimated that NCD accounted for 20% of the burden of disease in Burkina Faso as a percentage of total DALYs (disability adjusted life years), which captures both premature death and life lived with disease [31]. We found only 7% of the burden from premature deaths or YLL in Nouna were from NCD. Although the YLL component of DALYs in the WHO estimate were obtained by multiplying the number of deaths at each age by the global standard life expectancy for each age (rather than the regional life expectancy for each age), the sole use of premature death is likely to have missed substantial burden from life lived with disease. Causal studies on the temperature-NCD association would benefit from using DALYs or quality adjusted life years (QALY) as the outcome measure, considering a large proportion of the burden of NCD comes from life lived with disease. The YLL lifetable approach does not differentiate health and sociodemographic risk profiles for each individual. Unfortunately, the sample size was insufficient to further stratify NCD by age (i.e. elderly) or subgroups such as cardiovascular causes. The use of longer time series in the future with larger sample sizes is likely to enable such breakdowns by cause or age, reducing the uncertainty from wide confidence bounds, and supporting better quantification of heat impacts on NCD-YLL.

Conclusion

In rural Sub Saharan Africa, where NCD are not the main cause of premature death, we found that moderate and extreme heat exposure significantly increases excess daily premature mortality from NCD. As NCD prevalence increases in Africa due to demographic, dietary and lifestyle changes, climate change will increasingly contribute as a risk factor towards the burden of deaths from NCD. Subsistence farming communities in Africa, such as Nouna, would therefore benefit from the development of early preventive measures to curb heat-associated NCD deaths.

Competing interests

The authors declare they have no actual or potential competing financial interests

Acknowledgments

We thank Dr David Hondula for help obtaining temperature data from the National Climatic Data Centre, USA, and Drs Adrian Barnett and Cunrui Huang for statistical modelling advice.

Funding

AB was funded by the Klaus-Tschira Stiftung gGmbH (00.128.2008). Funders had no direct role in study design, data collection, data analysis, interpretation or writing of the report.

Data sharing

No additional data are available.

Author contributions

AB and RS developed the research idea with input from JR. Data were provided by AS. AB, MOS, JR and RS developed the modelling strategy. AB conducted the analysis, which was verified by MOS and RJ. AB wrote the manuscript. All authors contributed to revision of the manuscript.

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Figure 1: Association of RR of NCD-YLL to maximum temperature and lag days, with reference to 36.4°C for all ages, males and females.

Figure 2: Plots of 4-day (panel A-all age, B-male, and C-female), and 14-day (panel D-all age, E-male, and F-female) cumulative RR of NCD-YLL against maximum temperature (solid line) with 95% confidence bounds (grey area) for all ages, males and females in Nouna, Burkina Faso between 2000 and 2010. The reference temperature is 36.4°C. Note: to improve readability of the curves, the scales on the y-axis differ.

Figure 3: Delayed effects of maximum temperature on the RR of NCD-YLL (solid line) and 95% confidence bounds (grey area) for all age, males and females in Nouna, Burkina Faso, by lag 0-14 days. Plots A-all age, B-male, and C-female represent cold effects at 30°C (5^{th} percentile), and plots D-all age, E-male, and F-female represent heat effects at 41.7°C (95^{th} percentile) of maximum temperature. The reference temperature is 36.4°C. Note: to improve readability of the curves, the scales on the y-axis differ.

Table 1: Cause specific NCD outcomes with corresponding deaths and years of life lost. NCD accounted for 12% of total deaths, and 7% of total YLL in Nouna between 2000-2010

Table 2: Summary statistics of daily NCD deaths, NCD years of life lost and temperature in Nouna, Burkina Faso between 2000-2010.

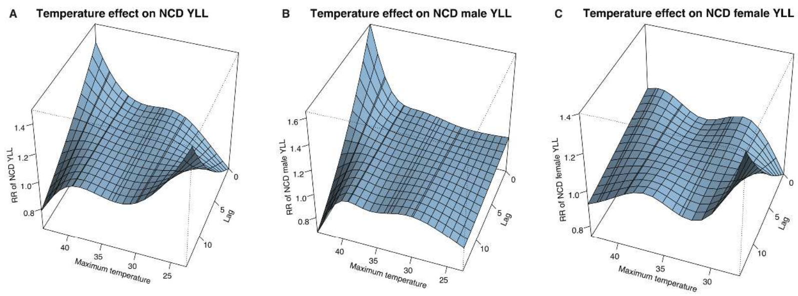
Table 3a: Cumulative relative risk (and 95% confidence bounds) of maximum temperature on non-communicable disease years of life lost in Nouna stratified across lag 0-4 and lag 0-14 days and gender between 2000-2010. Relative risks are presented for; heat effects as 38.9°C, 41.1°C and 41.7°C with reference to 36.4°C; cold effects as 30°C, 31.1°C and 33.3°C with reference to 36.4°C. Results controlled for long-term trends, season, day of the week, and heaping effect.

Table 3b: Cumulative excess average daily NCD-YLL (and 95% confidence bounds) stratified across lag 0-4 and lag 0-14 days and gender between 2000-2010. Relative risks were used to calculate excess average daily NCD-YLL as follows: (Average daily NCD-YLL of all-age, male or female * relative risk) – Average daily NCD-YLL. NCD-YLL are presented for; heat effects as 42.8°C, 38.9°C, 41.1°C and 41.7°C with reference to 36.4°C; cold effects as 30°C, 31.1°C, 33.3°C and 27.8°C with reference to 36.4°C. Results controlled for long-term trends, season, day of the week, and heaping effect.

Table 4a: Relative risk (and 95% confidence bounds) of maximum temperature on non-communicable disease years of life lost in Nouna stratified by individual lag days for all age, males and females between 2000-2010. Relative risks are presented for heat effects as 41.7°C (95^{th} percentile) with reference to 36.4°C, cold effects as 30°C (5^{th} percentile) with reference to 36.4°C. Results controlled for long-term trends, season, day of the week, and heaping effect.

Table 4b: Excess average daily NCD-YLL (and 95% confidence bounds) in Nouna stratified by individual lag days for all age, males and females between 2000-2010.

Relative risks were used to calculate excess average daily NCD-YLL as follows: (Average daily NCD-YLL of all-age, male or female * relative risk) – Average daily NCD-YLL. NCD-YLL are presented for heat effects as 41.7°C (95th percentile) with reference to 36.4°C, cold effects as 30°C (5th percentile) with reference to 36.4°C. Results controlled for long-term trends, season, day of the week, and heaping effect.



Association of RR of NCD-YLL to maximum temperature and lag days, with reference to 36.4°C for all ages, males and females.

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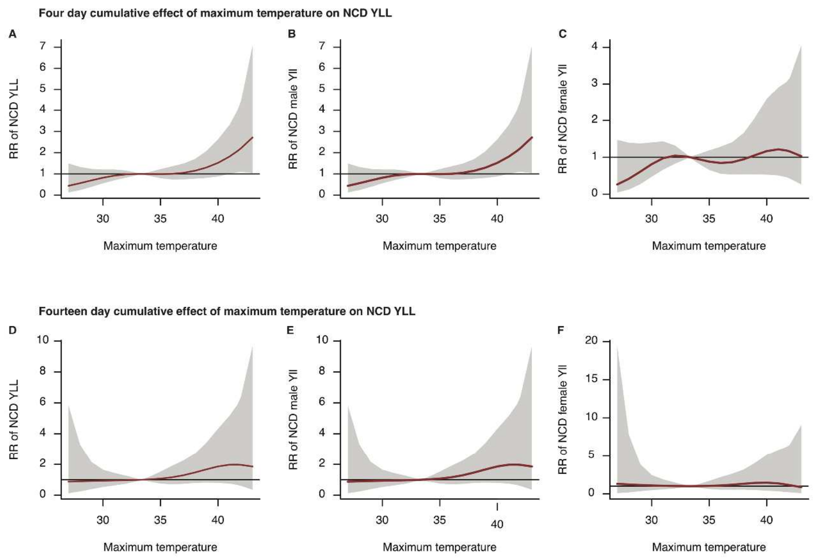

Plots of 4-day (panel A-all age, B-male, and C-female), and 14-day (panel D-all age, E-male, and F-female) cumulative RR of NCD-YLL against maximum temperature (solid line) with 95% confidence bounds (grey area) for all ages, males and females in Nouna, Burkina Faso between 2000 and 2010. The reference temperature is 36.4°C. Note: to improve readability of the curves, the scales on the y-axis differ.

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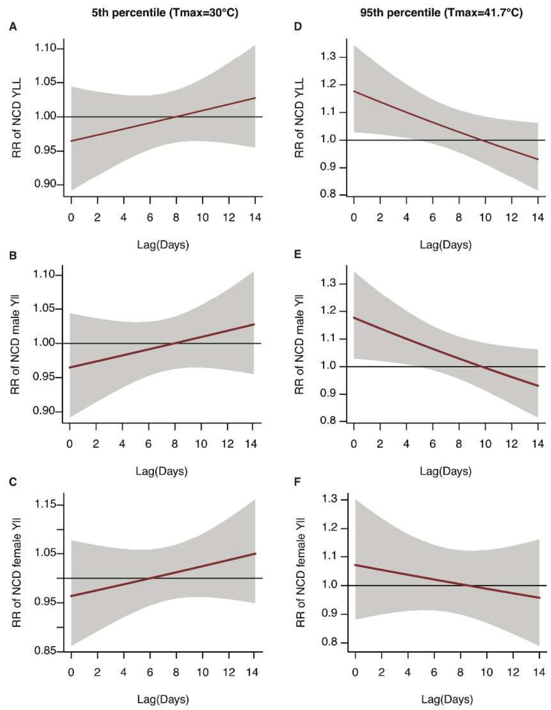

Delayed effects of maximum temperature on the RR of NCD-YLL (solid line) and 95% confidence bounds (grey area) for all age, males and females in Nouna, Burkina Faso, by lag 0-14 days. Plots A-all age, B-male, and C-female represent cold effects at 30°C (5th percentile), and plots D-all age, E-male, and F-female represent heat effects at 41.7°C (95th percentile) of maximum temperature. The reference temperature is 36.4°C. Note: to improve readability of the curves, the scales on the y-axis differ.

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Disease	Death count	Death (%)	YLL count	YLL (%)
Cardiovascular diseases	461	58	9095	50
Digestive diseases	137	17	3614	20
Malignant neoplasms	81	10	1720	9
Genitourinary diseases	38	5	1602	9
Neuropsychiatric conditions	37	5	1289	7
Congenital anomalies	8	1	481	3
Respiratory diseases	15	2	321	2
Diabetes mellitus	11	1	167	1
Other endocrine disorders	1	0	22	0
Musculoskeletal diseases	1	0	57	0
Total	**790**	**100**	**18367**	**100**

	Daily NCD and temperature descriptive statistics 2000-2010					
	Minimum	25%	50%	Mean	75%	Maximum
Daily number of NCD deaths						
Total	0	0	0	0.2	0	5
Male	0	0	0	0.1	0	4
Female	0	0	0	0.1	0	3
>65 years	0	0	0	0.1	0	3
Daily NCD years of life lost						
Total	0	0	0	4.6	0	154
Male	0	0	0	2.4	0	118.9
Female	0	0	0	2.1	0	127.5
>65 years	0	0	0	0.9	0	39.2
Temperature (°C)						
Daily minimum	3.3	21.1	22.8	23.1	25	32.8
Daily average	17.2	27.5	29.2	29.6	31.7	37.8
Daily maximum	22.8	33.3	36.4	36.1	38.9	43.9

	27.8°C (1st percentile)	30°C (5th percentile)	31.1°C (10th percentile)	33.3°C (25th percentile)	38.9°C (75th percentile)	41.4°C (90th percentile)	41.7°C (95th percentile)	42.8°C (99th percentile)
	34 days below 27.8°C	174 days below 30°C	325 days below 31.3°C	912 days below 33.3°C	883 days above 38.9°C	300 days above 41.4°C	189 days above 41.7°C	28 days above 42.8°C
	RR (95% CI)	RR (95% CI)	RR (95% CI)	RR (95% CI)	RR (95% CI)	RR (95% CI)	RR (95% CI)	RR (95% CI)
Lag structure 0-4								
All age	0.54 (0.22 to 1.36)	0.82 (0.56 to 1.21)	0.93 (0.72 to 1.21)	1.00 (0.99 to 1.01)	1.29 (0.81 to 2.04)	1.96 (1.05 to 3.67)	2.08 (1.08 to 4.01)	2.61 (1.07 to 6.35)
Male	0.53 (0.15 to 1.86)	0.77 (0.46 to 1.3)	0.88 (0.62 to 1.25)	1.00 (0.99 to 1.01)	1.36 (0.74 to 2.49)	2.56 (1.14 to 5.75)	2.86 (1.23 to 6.69)	4.60 (1.45 to 14.64)
Female	0.38 (0.10 to 1.41)	0.81 (0.47 to 1.4)	0.99 (0.68 to 1.43)	1.00 (0.99 to 1.01)	1.05 (0.54 to 2.04)	1.20 (0.49 to 2.98)	1.19 (0.46 to 3.05)	1.06 (0.30 to 3.79)
Lag structure 0-14								
All age	0.89 (0.22 to 3.67)	0.94 (0.53 to 1.65)	0.96 (0.64 to 1.42)	1.00 (0.99 to 1.01)	1.65 (0.82 to 3.35)	1.98 (0.71 to 5.54)	1.98 (0.66 to 5.91)	1.88 (0.41 to 8.75)
Male	0.71 (0.11 to 4.63)	0.91 (0.43 to 1.94)	0.97 (0.57 to 1.66)	1.00 (0.99 to 1.01)	1.57 (0.62 to 3.97)	2.11 (0.57 to 7.85)	2.14 (0.53 to 8.70)	2.16 (0.29 to 16.35)
Female	1.24 (0.16 to 9.27)	1.09 (0.49 to 2.46)	1.05 (0.59 to 1.84)	1.00 (0.98 to 1.02)	1.42 (0.50 to 3.99)	1.28 (0.28 to 5.97)	1.21 (0.24 to 6.17)	0.92 (0.10 to 8.30)

	27.8°C (1st percentile)	30°C (5th percentile)	31.1°C (10th percentile)	33.3°C (25th percentile)	38.9°C (75th percentile)	41.4°C (90th percentile)	41.7°C (95th percentile)	42.8°C (99th percentile)
	34 days below 27.8°C	174 days below 30°C	325 days below 31.3°C	912 days below 33.3°C	883 days above 38.9°C	300 days above 41.4°C	189 days above 41.7°C	28 days above 42.8°C
	YLL (95% CI)	YLL (95% CI)	YLL (95% CI)	YLL (95% CI)	YLL (95% CI)	YLL (95% CI)	YLL (95% CI)	YLL (95% CI)
Lag structure 0-4								
All age	-2.11 (-3.61 to 1.64)	-0.81 (-2.02 to 0.97)	-0.31 (-1.30 to 0.97)	0.00 (-0.03 to 0.03)	1.33 (-0.86 to 4.80)	4.44 (0.24 to 12.28)	4.98 (0.38 to 13.83)	7.39 (0.32 to 24.62)
Male	-1.13 (-2.04 to 2.06)	-0.55 (-1.30 to 0.72)	-0.29 (-0.92 to 0.59)	0.00 (-0.03 to 0.02)	0.86 (-0.62 to 3.57)	3.73 (0.33 to 11.39)	4.48 (0.54 to 13.65)	8.65 (1.07 to 32.73)
Female	-1.30 (-1.88 to 0.86)	-0.39 (-1.11 to 0.85)	-0.03 (-0.66 to 0.90)	0.01 (-0.01 to 0.03)	0.10 (-0.97 to 2.19)	0.43 (-1.08 to 4.16)	0.39 (-1.13 to 4.32)	0.12 (-1.48 to 5.86)
Lag structure 0-14								
All age	-0.48 (-3.6 to 12.27)	-0.28 (-2.15 to 3.01)	-0.20 (-1.64 to 1.95)	-0.01 (-0.06 to 0.04)	3.01 (-0.84 to 10.82)	4.53 (-1.33 to 20.89)	4.5 (-1.55 to 22.57)	4.07 (-2.73 to 35.66)
Male	-0.70 (-2.14 to 8.71)	-0.21 (-1.37 to 2.25)	-0.06 (-1.03 to 1.58)	0.00 (-0.04 to 0.04)	1.38 (-0.90 to 7.12)	2.67 (-1.03 to 16.44)	2.74 (-1.14 to 18.48)	2.78 (-1.72 to 36.83)
Female	0.50 (-1.75 to 17.37)	0.20 (-1.08 to 3.07)	0.09 (-0.86 to 1.77)	0.00 (-0.03 to 0.03)	0.87 (-1.05 to 6.28)	0.59 (-1.52 to 10.44)	0.44 (-1.60 to 10.86)	-0.18 (-1.89 to 15.32)

	All age		Male		Female	
	30°C (5th percentile)	41.7°C (95th percentile)	30°C (5th percentile)	41.7°C (95th percentile)	30°C (5th percentile)	41.7°C (95th percentile)
	RR (95% CI)		RR (95% CI)		RR (95% CI)	
lag0	0.96 (0.89 to 1.04)	1.18 (1.03 to 1.35)	0.96 (0.87 to 1.07)	1.24 (1.04 to 1.48)	0.96 (0.86 to 1.08)	1.07 (0.88 to 1.30)
lag1	0.97 (0.90 to 1.04)	1.16 (1.03 to 1.31)	0.97 (0.88 to 1.06)	1.21 (1.04 to 1.42)	0.97 (0.88 to 1.07)	1.06 (0.89 to 1.27)
lag2	0.97 (0.91 to 1.04)	1.14 (1.02 to 1.27)	0.97 (0.9 to 1.05)	1.19 (1.03 to 1.36)	0.98 (0.89 to 1.07)	1.05 (0.90 to 1.24)
lag3	0.98 (0.92 to 1.03)	1.12 (1.01 to 1.23)	0.98 (0.91 to 1.05)	1.16 (1.02 to 1.31)	0.98 (0.91 to 1.06)	1.05 (0.91 to 1.21)
lag4	0.98 (0.94 to 1.03)	1.10 (1.01 to 1.20)	0.98 (0.92 to 1.05)	1.13 (1.01 to 1.27)	0.99 (0.92 to 1.06)	1.04 (0.91 to 1.18)
lag5	0.99 (0.94 to 1.03)	1.08 (1.00 to 1.17)	0.99 (0.93 to 1.04)	1.10 (1.00 to 1.22)	0.99 (0.93 to 1.06)	1.03 (0.91 to 1.16)
lag6	0.99 (0.95 to 1.03)	1.06 (0.99 to 1.15)	0.99 (0.94 to 1.04)	1.08 (0.98 to 1.19)	1.00 (0.94 to 1.06)	1.02 (0.91 to 1.14)
lag7	1.00 (0.96 to 1.03)	1.05 (0.97 to 1.13)	0.99 (0.95 to 1.05)	1.05 (0.96 to 1.16)	1.01 (0.95 to 1.06)	1.01 (0.91 to 1.13)
lag8	1.00 (0.96 to 1.04)	1.03 (0.96 to 1.11)	1.00 (0.95 to 1.05)	1.03 (0.93 to 1.13)	1.01 (0.96 to 1.07)	1 .00 (0.90 to 1.12)
lag9	1.00 (0.96 to 1.05)	1.01 (0.94 to 1.10)	1.00 (0.95 to 1.06)	1.00 (0.91 to 1.11)	1.02 (0.96 to 1.08)	1 .00 (0.89 to 1.12)
lag10	1.01 (0.96 to 1.06)	1.00 (0.91 to 1.09)	1.01 (0.95 to 1.07)	0.98 (0.88 to 1.09)	1.02 (0.96 to 1.09)	0.99 (0.87 to 1.12)
lag11	1.01 (0.96 to 1.07)	0.98 (0.89 to 1.08)	1.01 (0.94 to 1.08)	0.96 (0.85 to 1.08)	1.03 (0.96 to 1.11)	0.98 (0.85 to 1.13)
lag12	1.02 (0.96 to 1.08)	0.96 (0.86 to 1.07)	1.02 (0.94 to 1.10)	0.93 (0.81 to 1.07)	1.04 (0.96 to 1.12)	0.97 (0.83 to 1.14)
lag13	1.02 (0.96 to 1.09)	0.95 (0.84 to 1.07)	1.02 (0.93 to 1.12)	0.91 (0.78 to 1.06)	1.04 (0.95 to 1.14)	0.97 (0.81 to 1.15)
lag14	1.03 (0.96 to 1.11)	0.93 (0.82 to 1.06)	1.03 (0.93 to 1.13)	0.89 (0.75 to 1.06)	1.05 (0.95 to 1.16)	0.96 (0.79 to 1.16)

	All age		Male		Female	
	30°C (5th percentile)	**41.7°C (95th percentile)**	**30°C (5th percentile)**	**41.7°C (95th percentile)**	**30°C (5th percentile)**	**41.7°C (95th percentile)**
	174 days below 30°C	189 days above 41.7°C	174 days below 30°C	189 days above 41.7°C	174 days below 30°C	189 days above 41.7°C
	YLL (95% CI)		YLL (95% CI)		YLL (95% CI)	
lag0	-0.16 (-0.50 to 0.20)	0.81 (0.13 to 1.59)	-0.09 (-0.31 to 0.16)	0.58 (0.11 to 1.15)	-0.08 (-0.29 to 0.16)	0.15 (-0.25 to 0.63)
lag1	-0.14 (-0.45 to 0.19)	0.72 (0.12 to 1.41)	-0.08 (-0.28 to 0.15)	0.51 (0.09 to 1.01)	-0.06 (-0.26 to 0.15)	0.13 (-0.23 to 0.56)
lag2	-0.12 (-0.40 to 0.17)	0.63 (0.09 to 1.24)	-0.07 (-0.25 to 0.13)	0.44 (0.07 to 0.87)	-0.05 (-0.23 to 0.14)	0.11 (-0.21 to 0.50)
lag3	-0.10 (-0.35 to 0.16)	0.55 (0.07 to 1.08)	-0.06 (-0.22 to 0.12)	0.38 (0.05 to 0.75)	-0.04 (-0.20 to 0.13)	0.10 (-0.20 to 0.43)
lag4	-0.08 (-0.30 to 0.15)	0.46 (0.04 to 0.93)	-0.05 (-0.19 to 0.11)	0.31 (0.02 to 0.64)	-0.03 (-0.17 to 0.13)	0.08 (-0.19 to 0.38)
lag5	-0.06 (-0.25 to 0.14)	0.38 (0.00 to 0.79)	-0.04 (-0.17 to 0.10)	0.25 (-0.01 to 0.54)	-0.01 (-0.14 to 0.12)	0.06 (-0.18 to 0.33)
lag6	-0.04 (-0.22 to 0.14)	0.30 (-0.06 to 0.68)	-0.03 (-0.15 to 0.10)	0.19 (-0.05 to 0.45)	0.00 (-0.12 to 0.12)	0.04 (-0.18 to 0.30)
lag7	-0.02 (-0.19 to 0.16)	0.21 (-0.12 to 0.58)	-0.01 (-0.13 to 0.11)	0.12 (-0.10 to 0.37)	0.01 (-0.10 to 0.13)	0.03 (-0.19 to 0.27)
lag8	0.00 (-0.17 to 0.18)	0.13 (-0.20 to 0.50)	0.00 (-0.12 to 0.12)	0.07 (-0.16 to 0.31)	0.03 (-0.09 to 0.14)	0.01 (-0.21 to 0.26)
lag9	0.02 (-0.16 to 0.21)	0.06 (-0.30 to 0.44)	0.01 (-0.12 to 0.14)	0.01 (-0.22 to 0.26)	0.04 (-0.08 to 0.17)	-0.01 (-0.24 to 0.25)
lag10	0.04 (-0.16 to 0.26)	-0.02 (-0.40 to 0.39)	0.02 (-0.13 to 0.17)	-0.05 (-0.30 to 0.23)	0.05 (-0.08 to 0.19)	-0.02 (-0.27 to 0.26)
lag11	0.06 (-0.17 to 0.31)	-0.10 (-0.51 to 0.36)	0.03 (-0.14 to 0.20)	-0.10 (-0.37 to 0.2)	0.07 (-0.08 to 0.22)	-0.04 (-0.31 to 0.27)
lag12	0.08 (-0.18 to 0.36)	-0.17 (-0.62 to 0.33)	0.04 (-0.15 to 0.24)	-0.16 (-0.45 to 0.17)	0.08 (-0.09 to 0.26)	-0.06 (-0.35 to 0.29)
lag13	0.11 (-0.19 to 0.42)	-0.25 (-0.74 to 0.31)	0.05 (-0.16 to 0.28)	-0.21 (-0.52 to 0.15)	0.09 (-0.10 to 0.30)	-0.07 (-0.40 to 0.31)
lag14	0.13 (-0.21 to 0.49)	-0.32 (-0.85 to 0.29)	0.06 (-0.17 to 0.32)	-0.26 (-0.60 to 0.13)	0.11 (-0.11 to 0.34)	-0.09 (-0.44 to 0.34)

STROBE Statement—Checklist of items that should be included in reports of ***cohort studies***

	Item No	Recommendation
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract [within title page and abstract under 'design']
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found [see abstract under 'results']
Introduction		
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported [pg 4]
Objectives	3	State specific objectives, including any prespecified hypotheses [pg 5]
Methods		
Study design	4	Present key elements of study design early in the paper [pg 5-8]
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection [pg 5-7]
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up [pg 5-7]
		(*b*) For matched studies, give matching criteria and number of exposed and unexposed [n/a]
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable [pg 5-8]
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group [pg 5-8]
Bias	9	Describe any efforts to address potential sources of bias [n/a]
Study size	10	Explain how the study size was arrived at [n/a]
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why [pg 8-9]
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding [for all statistical methods *a-e*: pg 7-9]
		(*b*) Describe any methods used to examine subgroups and interactions
		(*c*) Explain how missing data were addressed
		(*d*) If applicable, explain how loss to follow-up was addressed
		(*e*) Describe any sensitivity analyses
Results		
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed [n/a]
		(b) Give reasons for non-participation at each stage
		(c) Consider use of a flow diagram
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders [for all descriptive data *a-c*: pg 9, Table 2]
		(b) Indicate number of participants with missing data for each variable of interest
		(c) Summarise follow-up time (eg, average and total amount)
Outcome data	15*	Report numbers of outcome events or summary measures over time [pg 9-11, Table 1,2]
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and

		their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included [all main results *a-c*: pg 9-11, Tables 3-4, Figures 1-3]
		(*b*) Report category boundaries when continuous variables were categorized
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses [pg 11]
Discussion		
Key results	18	Summarise key results with reference to study objectives [pg 11]
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias [pg 14]
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence [pg 11-13]
Generalisability	21	Discuss the generalisability (external validity) of the study results [pg 14]
Other information		
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based [pg 15]

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at http://www.strobe-statement.org.