TITLE: Will climate change increase or decrease suicide rates? The differing effects of geographical, seasonal, and irregular variation in temperature on suicide incidence

Matt N. Williams[1], School of Psychology, Massey University, New Zealand

Stephen R. Hill, School of Psychology, Massey University, New Zealand

John Spicer, School of Psychology, Massey University, New Zealand

[1]Corresponding author.

School of Psychology, Massey University

Private Bag 102904

Auckland 0745

New Zealand

+64 21 059 8625

M.N.Williams@massey.ac.nz

1. Abstract

The effect of environmental temperature on suicide risk is an important issue given the increase in global temperatures expected over the following century. Previous research has produced conflicting findings: Studies concerned with temporal variation in temperature and suicide have tended to find a positive relationship, while those concerned with geographical variation in temperature and suicide have tended to find a negative relationship. In this study, we aimed firstly to estimate the relationship between suicide incidence and three components of variation in temperature: Irregular, seasonal, and geographical. Secondly, we aimed to critically examine what this information can (and cannot) tell us about the likely effects of anthropogenic climate change on suicide rates. Suicide data from New Zealand for the period 1988 to 2007 were collated according to date of death and district and compared with temperature data from the same period. Using generalized linear mixed models, we found that irregular variation in temperature was positively related to suicide incidence, with about 1.8% more suicides for every 1°C increase in temperature. On the other hand, seasonal variation in temperature had virtually no linear relationship with suicide incidence, and when controlling for demographic differences, geographical variation in temperature was *negatively* related to suicide incidence. We conclude that differences in both the sign and the direction of the effects of different forms of variation in temperature mean that it is very difficult to predict how climate change will affect risk of suicide.

Keywords

1. Climate change
2. Global warming
3. Suicide
4. Temperature

2. Introduction

There is a substantial literature concerned with the relationship between climatic factors and the incidence of suicide (for reviews see Deisenhammer 2003; Dixon and Kalkstein 2009), with much of this literature concerned with the effect of temperature on suicide risk. An apparent relationship between temperature and suicide leads naturally to questions about how anthropogenic climate change will affect suicide rates. At least one recent study has suggested that global warming will increase the risk of suicide (Preti et al. 2007). This said, the reviews by Deisenhammer (2003) and Dixon and Kalkstein (2009) both noted that existing findings concerned with the effect of temperature on suicide are contradictory: A number of studies have found a positive relationship between temperature and suicide incidence (Maes et al. 1994; Yan 2000; Page et al. 2007; Yang et al. 2011; Likhvar et al. 2011; Müller et al. 2011), while others have found a negative relationship (Robbins et al. 1972; Rotton 1986; Souêtre et al. 1990; Lester 1999).

This apparent paradox can be at least partially resolved by noting an important difference between the studies finding a negative relation and those finding a positive relationship. Specifically, studies finding a negative effect tend to be those estimating the effects of *geographical* variation in temperature (i.e., comparing suicide rates across areas with different mean temperatures), whereas those finding a positive effect tend to be concerned with the effects of *temporal* variation in temperature (i.e., comparing different time periods within the same geographical area).

In an example of the geographical comparison approach, Lester (1999) compared 62 nations and found that temperature was negatively correlated with suicide rates, $r = –.59$. This finding was similar to that of an earlier international study finding a correlation of -0.58 between suicide rate in 1965 and a 6-point scale of climate warmth (Robbins et al. 1972). Another study of 48 countries by Rotton (1986) found a negative correlation of similar magnitude between mean January temperatures and suicide rate, $r = –.58$. A study of 19 French regions also found that regional mean temperature was negatively correlated with suicide rates, $r = –0.5$ in both 1975 and 1983 (Souêtre et al. 1990). Similarly, an Italian study found a correlation of –.45 between annual mean minimum temperature and suicide rate across 17 towns, although this relationship was not quite statistically significant (Preti 1998).

On the other hand, studies of the effects of temporal variation in temperature have tended to find a positive relationship between temperature and suicide rates. Temporal variation in temperature can be broken down into further sub-components, including seasonal

variation and irregular (random) variation. Existing studies suggest that the positive effect of temporal variation seems to hold across these two components. In an example of a study of irregular daily variation in temperature, Page et al. (2007) found a positive relationship between mean daily temperature and suicide risk in Britain, albeit only above a certain threshold: Every 1°C increase in mean daily temperature above 18°C was associated with a 3.8% increase in suicides, when controlling for month. Ajdacic-Gross et al. (2007) likewise found a significant positive association between monthly temperature and both male and female monthly suicides in Switzerland over 1881–2000, after fitting an ARIMA model to each variable to remove seasonal, trend and autocorrelative patterns. Studies of the effects of irregular daily variation in temperature in Mittelfranken, Germany (Müller et al. 2011) and Japan (Likhvar et al. 2011) likewise found positive effects on suicide incidence, as did a study using data from both Toronto and Jackson, Mississippi (Dixon et al. 2014).

A seasonal pattern in suicide deaths is well established, with a peak in spring (see Ajdacic-Gross et al. 2010 for a review). While most studies of seasonality in suicide have examined the univariate distribution of suicides, a small number of studies have specifically assessed the relationship between seasonal variation in temperature and suicide. Maes et al. (1994) showed that violent suicide rate, sunshine duration and ambient temperature shared a common annual rhythm in Belgium. Similarly, Preti (1997) found a positive correlation of 0.67 between mean temperature (across the 12 months of the calendar year) in Italy and the mean number of suicides. This said, the fact that suicides tend to peak in the spring rather than summer suggests that a linear effect of temperature is not the major factor driving seasonality in suicides.

Admittedly, not all studies on the topic fit the pattern of a positive effect of temporal variation in temperature, but a negative effect of geographical variation. A study in Queensland found a positive relationship between geographical variation in temperature and suicide incidence (Qi et al. 2009). Similarly, not all temporal studies have found positive effects of temperature: A study of suicides in North Carolina found no significant effect of temperature on suicide incidence (Zung and Green 1974), nor did a study of a township in Greenland (Grove and Lynge 1979). Overall, however, the pattern of a negative effect of geographical variation in temperature and a positive effect of temporal variation in temperature seems quite well substantiated in most locations.

No general review of the effect of climatic factors other than temperature on suicide incidence is provided here for brevity's sake. However, one climatic factor is of particular relevance: Solar radiation. Global solar radiation (Ruuhela et al. 2008; Müller et al. 2011) is

positively related to suicide incidence, as is number of sunshine hours (Vyssoki et al. 2012). Solar radiation and temperature are also related. Therefore, solar radiation is a potential confound of the temperature-suicide relationship. As such, it can serve a useful role as a control in multivariable analyses.

2.1 Explanations of the effects of temperature on suicide

The mechanism linking temperature and suicide risk is not well understood. A number of theories seek to explain seasonality in suicides, including greater perceived opportunity of some suicide methods in warmer weather (Ajdacic-Gross et al. 2010), seasonal changes in serotonergic function (Maes et al. 1995), and Durkheim's (1897) theory that the spring suicide peak is caused by a greater intensity of social life. A recently proposed theory relates to the observation that brown adipose tissue is activated in cold temperatures to produce non-shivering thermogenesis (Holopainen et al. 2013; 2014). Holopainen et al. suggest that, in spring, rapidly increasing temperatures in the absence of an inhibitory long photoperiod may result in relative over-activation of brown adipose tissue, a condition believed to cause symptoms similar to those of depression. This said, a suicidogenic effect of over-activation of brown adipose tissue relative to ambient temperatures cannot explain why geographical variation in temperature and suicide are negatively related. In general, no complete single explanation for the varying relationships between suicide and different components of variation in temperature exists.

2.2 Consideration of global climate change

Research studies concerned with the effects of temperature on intra-personal violence have thus far given little direct focus to the problem or implications of climate change, aside from passing mentions of the issue (e.g., Page et al. 2007; Törő et al. 2009; Kim et al. 2011). One exception is a study using national Italian data (Preti et al. 2007). Preti et al claimed to have found evidence for a link between global warming and an enhanced risk of suicide. However, Preti et al. did not consider the issue of the conflicting effects of geographical and temporal variation in temperature.

2.3 Aims of the current study

This study aimed to estimate the relationship between the incidence of suicide and three components of variation in temperature in New Zealand: Irregular variation, seasonal variation, and geographical variation. We also aimed to critically examine what the resulting

information can (and cannot) tell us about the likely effects of future climate change on suicide rates.

3. Methods

3.1 Suicide data

A listing of nationwide suicide deaths from New Zealand was obtained from the Ministry of Health for the period 1 January 1988 to 31 December 2007. The date of death, gender, and territorial local authority (i.e., district) of residence of the deceased were included. Deaths due to late effects of self-harm were excluded. These data were then collated into a count of suicides on each date and for each of the 67 current districts of New Zealand.

3.2 Meteorological data

Meteorological data were obtained from the National Institute of Water and Atmospheric Research's virtual climate network, which covers New Zealand on a regular 5km grid. The virtual station closest to the town centre of the largest town or city within each district was used to represent the given district. Daily mean temperatures were calculated as the mean of the daily minimum and maximum temperatures. Seasonal norm temperatures were obtained by calculating the mean temperature (across the entire period of 20 years) for each day of the 365 days of the calendar year in each district, and then subtracting the overall mean temperature for that district. In order to operationally define irregular variation in temperatures, the temperature anomaly for every date-district combination was defined as the difference between the observed temperature on a given date, and the average temperature for that location and day of the year.

3.3 Population data

Annual population estimates by district were obtained from Statistics New Zealand Statistics New Zealand. Demographic (age and ethnicity) information for each district as at the 1996, 2001 and 2006 censuses was obtained from the Statistics New Zealand website (Statistics New Zealand 2013).

3.4 Data analysis

Data analysis was completed in R version 3.0.2 (R Core Team 2013), with the lme4 package version 1.0-5 (Bates et al. 2013) used for generalized linear mixed models. A Poisson distribution with a log link was used for mixed models. The effect of population size was controlled in all substantive analyses, following a log transformation to allow population size to have an additive effect. Spline analysis was completed in the crs package (Nie and Racine 2012), with automatic selection of the number of segments and polynomial form via Kullback-Leibler cross-validation.Visually-weighted regression (Hsiang 2013) was completed using R code by Schönbrodt (2012), with the span for the loess smoother selected using the bias-corrected Akaike information criterion, as implemented in the fANCOVA package (Wang 2010).

For further information about methods and data sources please refer to the Electronic Supplementary Materials.

4. Results

In the 20 years surveyed, 9984 suicides were recorded across the 67 districts of New Zealand (excluding a further 47 suicides with a district of "overseas/other" listed). A clear majority of these suicides (78%) were by males. The mean national suicide rate over the study period (1988 to 2007) was 13.3 suicides per 100,000 per annum. Over the same period, the mean temperature across all 67 districts and 7305 days of the study period was 12.7°C (SD = 4.3°C).

The first analysis of the effect of temperature was a simple one in which variation in temperature was not isolated into geographical, seasonal, and irregular components. This was completed by specifying a Poisson generalized linear mixed model, with the number of suicides for each date and district in the dataset as the response, and the only predictors being mean temperature and the logarithm of population size. This model produced a positive but very small coefficient for temperature of β = 0.004, with the 95% confidence interval including zero, CI [-0.001, 0.009]. While this finding might seem to suggest no or little effect of temperature on suicide incidence, the sections that follow show how different types of variation in temperature appear to have quite different effects on the incidence of suicide.

4.1 Effects of irregular variation in temperature

The effect of irregular variation in temperature was examined by entering temperature anomalies as a predictor into a Poisson generalized linear mixed model, with population controlled, and the intercept free to vary across districts. The number of suicides occurring for each date-district combination was the response variable. In this model, the coefficient of 0.018, 95% CI [0.009, 0.027] for irregular variation in temperature suggested that every 1°C temperature increase was associated with approximately 1.8% more suicides.

The estimated effect of temperature was robust to alternative modelling choices, with the point estimate remaining at 0.018 (within rounding) given alternative strategies such as adding a control for radiation and using a negative binomial rather than Poisson model. An alternative non-linear analysis was also completed, estimating the relationship between nationally averaged temperature anomaly and national suicide rate by date using loess smoothing (see Figure 1). As is visible, the relationship between temperature anomaly and suicide incidence is fairly well approximated by a linear form. Indeed, aspline analysis of suicide rate per capita (across all dates and districts) regressed on temperature anomaly also suggested that a simple linear model was the best fit, justifying the linear model reported. Figure 1 also shows that while the effect of irregular variation temperature can be estimated with reasonable precision for temperature anomalies between roughly -3°C and 3°C, the effects of temperatures outside this range are subject to much greater uncertainty.

We also attempted to determine whether irregular temperature had delayed effects on suicide incidence by calculating lagged temperature terms. We added lagged temperature terms up to a lag of seven days to the generalized linear mixed model mentioned above. In this model, the contemporaneous effect of temperature remained similar, but the lagged effects were all small and not statistically significant.

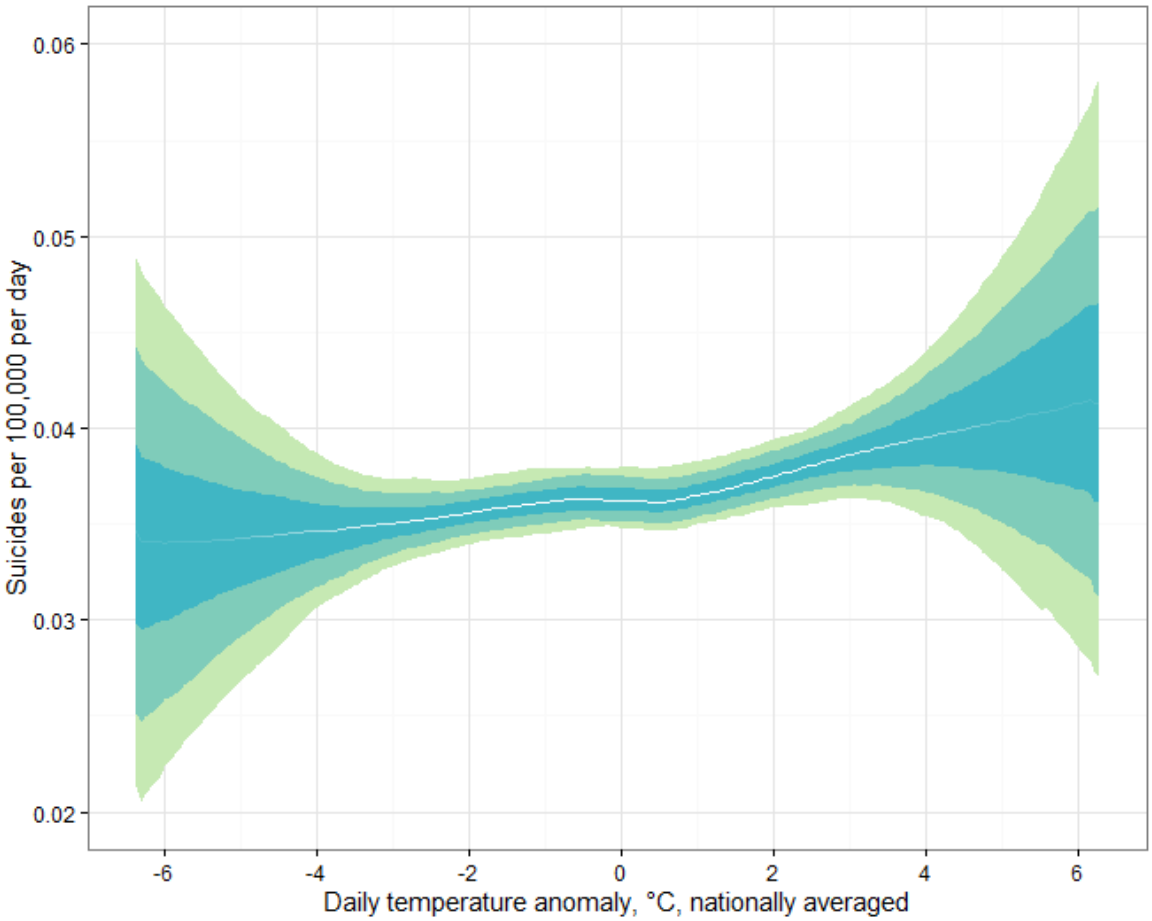

Fig. 1 Visually-weighted non-linear regression analysis of the effects of irregular variation in temperature. Model estimated using loess smoothing (degree = 2, span = 0.9). The line of best fit is in white. The shaded bands indicate the regions within 1, 2, and 3 standard errors of the estimate.

4.2 Effects of seasonal variation in temperature

The mean daily suicides rates and mean temperatures by month, across all districts, are displayed in Figure 2. The seasonal pattern is qualitatively in accordance with the usual findings in the field: The number of suicides peaks in the Southern Hemisphere spring, with a trough in winter. However, the magnitude of the seasonal variation was small.

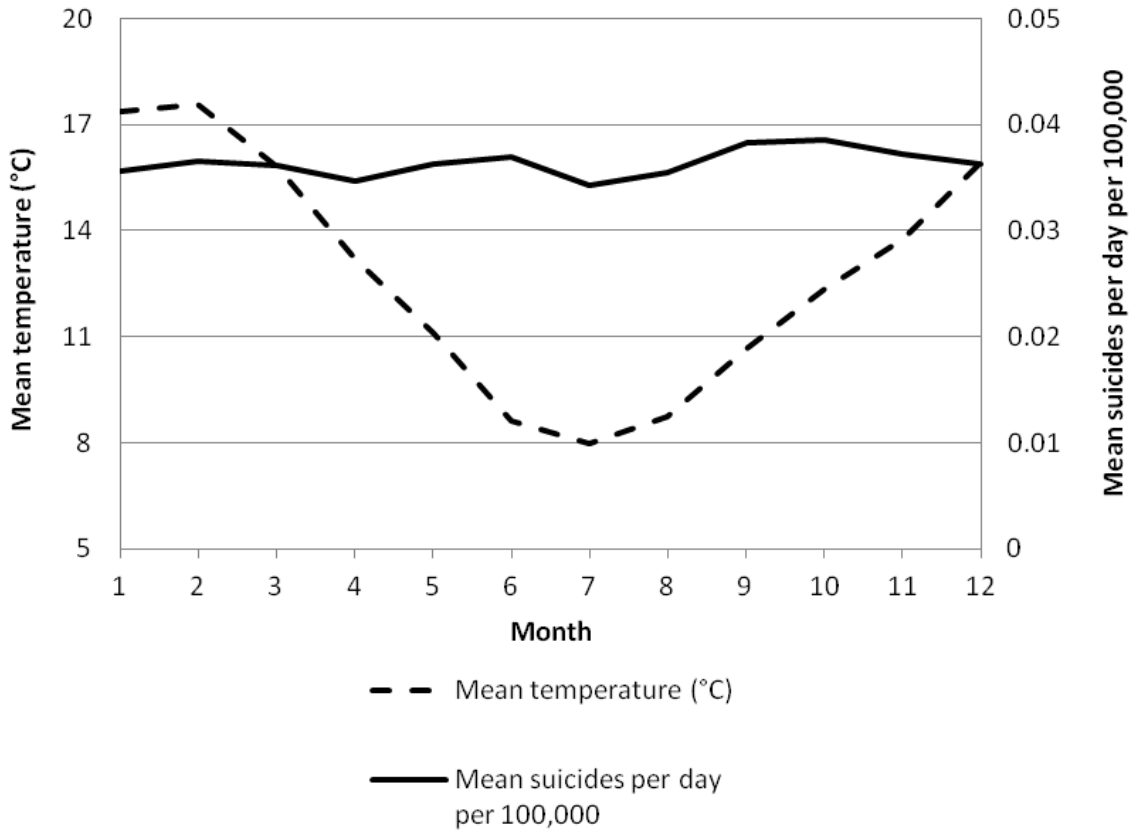

Fig. 2 Mean daily suicides per 100,000 and temperature by month

The impression of a weak relationship between seasonal variation in temperature and suicide incidence was corroborated by a generalized linear mixed model in which the total number of suicides summed over the 20 occurrences of each of the 365 days of the calendar year (across the entire study period) for each district was the response variable, while seasonal norm temperatures and population size were predictors. The intercept was specified as a random effect across districts. The resulting estimated effect of seasonal variation in temperature was tiny, $\hat{\beta} = 4.63 \times 10^{-4}$, $p = .881$, 95% CI [-0.006, 0.007].

4.3 Geographical variation in temperature

A scatter plot of mean temperature by geographical location versus suicide rate is displayed in Figure 3. No clear relationship is evident. The correlation between geographical mean temperature and suicide rate was indeed close to zero, $r(N = 67) = .094$, 95% CI [-.150, .326]. Similarly, a negative binomial model with a control for population suggested a small effect of temperature, $\hat{\beta} = .005$, with a wide 95% confidence interval that spanned zero, [-0.022, 0.032].

However, an alternative analysis was also completed with controls for age and ethnicity (European percentage of the population, Māori percentage of the population, percentage aged 15–39, percentage aged 40–64, and percentage aged 65+). In this analysis, the estimated effect of temperature became negative, $\hat{\beta}$ = -0.034, 95%CI [-0.067, -0.001]. Further adding a control for radiation resulted in the estimate remaining negative but falling outside significance, $\hat{\beta}$ = -0.026, 95%CI [-0.065, 0.012], with the effect of radiation likewise being non-significant, $\hat{\beta}$ = -0.020, 95%CI [-0.073, 0.033].

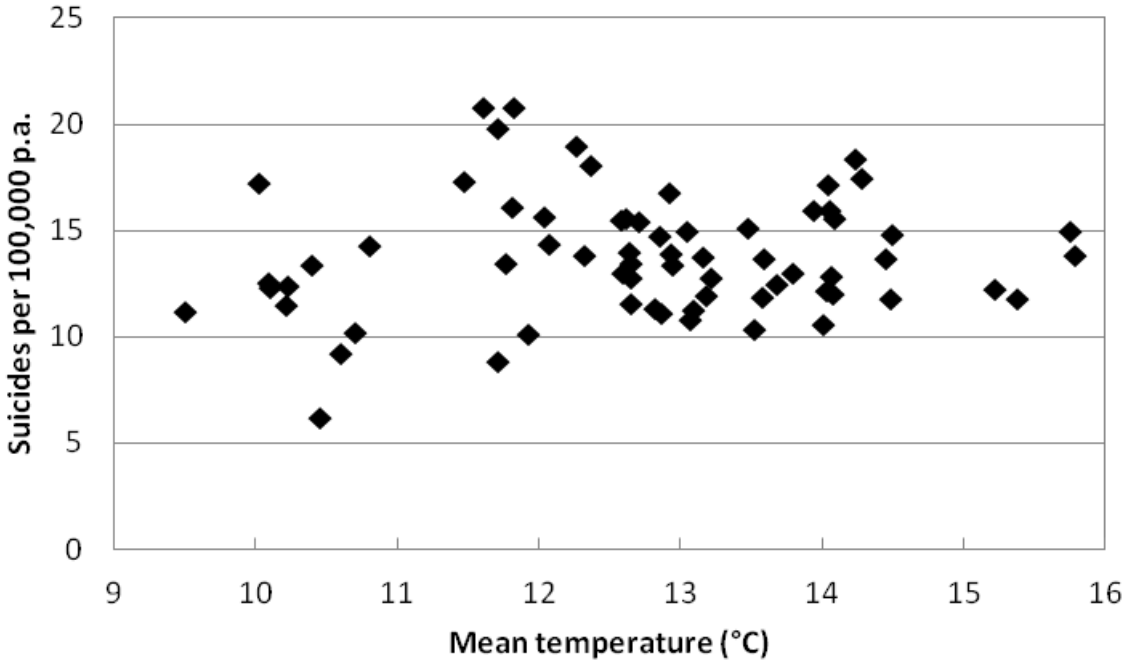

Fig. 3 Geographical variation in temperature versus suicide rate

5. Discussion

In this study, irregular variation in temperature had a positive relationship with suicide incidence, with approximately 1.8% more suicides for every 1°C increase in temperature. The size of this estimate was fairly consistent with those of previous studies (e.g., Deisenhammer 2003; Kim et al. 2011). We did not find evidence of the non-linear relationship between temperature and suicide incidence reported by Page et al. (2007). We also found no evidence for any substantial lagged effect of irregular variation in temperature, a finding similar to that of Likhvar et al. (2011) and Kim et al. (2011).

On the basis of the apparent positive effect of irregular variation in temperature, it would be tempting to conclude that global warming will increase the incidence of suicides. However, this conclusion is contradicted by our analyses of seasonal and geographical variation in temperature and suicide. Seasonal variation in suicide deaths did roughly follow the pattern generally found in the literature of a peak in spring and a trough in winter (Chew and McCleary 1995), but in accordance with a previous study in New Zealand (Yip et al. 1998), the magnitude of seasonal variation in suicide incidence was very small. Furthermore, seasonal variation in temperature had a relationship with suicide incidence that was close to zero: That is, hotter times of the year were not consistently associated with higher suicide risk

The relationship between geographical variation in temperature and suicide incidence differed even more greatly from that of irregular variation in temperature. While there was little evidence of any relationship at a bivariate level, controlling for age and ethnic differences across regions resulted in the relationship becoming negative: warmer areas had *lower* suicide rates. This finding was in accordance with prior studies finding a negative relationship between geographical variation in temperature and suicide rates (Rotton 1986; Souêtre et al. 1990; Lester 1999). The estimated effect became non-significant when controlling for radiation, although the effect of radiation was likewise not significant. As such, it is difficult to confirm whether the apparent relationship between geographical variation in temperature and suicide is due to a unique effect of temperature, or just to differences in sunlight exposure. Different types of variation in temperature therefore appeared to have quite different effects on suicide incidence in this study. One potential explanation is that one or more of the analyses were confounded. The effects of irregular variation in temperature seem least likely to be confounded, given that short-term day-to-day temporal variation in temperature is random, relatively unpredictable, and not strongly influenced by or related to human factors (e.g., economic, demographic, or social variables). Furthermore, the variables that do explain irregular variation in temperature are meteorological in nature, and can be controlled for statistically (solar radiation being a prime example). On the other hand, analyses of geographical variation are much more susceptible to confounding by demographic, economic, and social variables that differ across regions and affect suicide rates. In the current study, we controlled for two plausible confounds (age and ethnicity), but it is difficult to rule out the possibility of other confounds. Statistical control for other potential confounds (e.g., economic production, differences in divorce rates) was difficult to apply given the lack of information available about inter-district differences in many social and demographic variables. The lack of such controls in the geographical

analysis is a limitation of this study. The effect of seasonal variation in temperature on suicide incidence is likewise somewhat susceptible to confounding by seasonal and calendar-related cycles in human activity that are not caused by temperature.

Counteracting the potential confounding problem relating to analyses of seasonal and (especially) geographical variation is that these analyses can potentially provide information about how humans adapt to long-term, sustained climatic differences. Indeed, the negative relationship between geographical variation in temperature and suicide incidence hints at the presence of adaptation mechanisms to warmer temperatures that inhibit suicide risk in the long term. At the very least, this finding means that we should be cautious about assuming that the positive effect of irregular variation in temperature on suicide incidence implies that climate change will increase suicide risk. Until the reasons for the apparently conflicting effect of geographical variation in temperature can be identified, such an inference does not seem well justified.

What would be particularly useful is a theoretical account that can explain all of the various empirical regularities established with respect to the relationship between temperature and suicide incidence: The negative relationship between geographical variation in temperature and suicide, the positive relationship between irregular variation in temperature and suicide, and the established seasonal pattern variation in suicide rates (i.e., a springtime peak and winter nadir). Existing explanations generally attempt only to explain one or two of those regularities; in fact most theoretical accounts focus primarily on explaining seasonality in suicides. Seasonal variation in suicide has been explained as being caused by differences in perceived availability of some suicide methods (Ajdacic-Gross et al. 2010), by over-activation of brown adipose tissue in spring (Holopainen et al. 2013), or by changes in serotonergic functioning (Maes et al. 1995). The development of a coherent theoretical account explaining the relationships observed between different types of variation in temperature and suicide incidence could provide guidance when attempting to generate predictions about the impacts of climate change, and is an important avenue for future research. We did not attempt to produce or test such a framework, which was a limitation of this study. In the absence of a coherent theoretical account, differences in both the size and the direction of the effects of different types of variation in temperature means that it remains difficult to predict both the direction and the size of the future effect of climate change on suicide incidence.

6. Acknowledgements

We thank Jane Perrott and Chris Lewis at the Ministry of Health for providing suicide mortality data, Richard Speirs at Statistics New Zealand for providing population data, and two anonymous reviewers for helpful feedback.

7. References

8. Ajdacic-Gross V, Bopp M, Ring M, et al (2010) Seasonality in suicide – A review and search of new concepts for explaining the heterogeneous phenomena. Soc Sci Med 71:657–666. doi: 10.1016/j.socscimed.2010.05.030

9. Ajdacic-Gross V, Lauber C, Sansossio R, et al (2007) Seasonal associations between weather conditions and suicide—evidence against a classic hypothesis. Am J Epidemiol 165:561–569. doi: 10.1093/aje/kwk034

10. Bates D, Maechler M, Bolker B, Walker S (2013) lme4: Linear mixed-effects models using Eigen and S4. http://cran.r-project.org/web/packages/lme4/index.html

11. Chew KSY, McCleary R (1995) The spring peak in suicides: A cross-national analysis. Soc Sci Med 40:223–230. doi: 10.1016/0277-9536(94)E0070-9

12. Deisenhammer EA (2003) Weather and suicide: the present state of knowledge on the association of meteorological factors with suicidal behaviour. Acta Psychiatr Scand 108:402–409. doi: 10.1046/j.0001-690X.2003.00209.x

13. Dixon PG, Kalkstein AJ (2009) Climate suicide relationships: A research problem in need of geographic methods and cross-disciplinary perspectives. Geogr Compass 3:1961–1974. doi: 10.1111/j.1749-8198.2009.00286.x

14. Dixon PG, Sinyor M, Schaffer A, et al (2014) Association of weekly suicide rates with temperature anomalies in two different climate types. Int J Environ Res Public Health 11:11627–11644. doi: 10.3390/ijerph111111627

15. Durkheim É (1897) Le Suicide. Léo, Paris, France

16. Grove O, Lynge J (1979) Suicide and attempted suicide in Greenland. Acta Psychiatr Scand 60:375–391. doi: 10.1111/j.1600-0447.1979.tb00286.x

17. Holopainen J, Helama S, Björkenstam C, Partonen T (2013) Variation and seasonal patterns of suicide mortality in Finland and Sweden since the 1750s. Environ Health Prev Med 18:494–501. doi: 10.1007/s12199-013-0348-4

18. Holopainen J, Helama S, Partonen T (2014) Does diurnal temperature range influence seasonal suicide mortality? Assessment of daily data of the Helsinki metropolitan area from 1973 to 2010. Int J Biometeorol 58:1039–1045. doi: 10.1007/s00484-013-0689-0

19. Hsiang SM (2013) Visually-weighted regression. http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2265501

20. Kim Y, Kim H, Kim D-S (2011) Association between daily environmental temperature and suicide mortality in Korea (2001–2005). Psychiatry Res 186:390–396. doi: 10.1016/j.psychres.2010.08.006

21. Lester D (1999) Climatic data and national suicide and homicide rates. Percept Mot Skills 89:1036. doi: 10.2466/pms.1999.89.3.1036

22. Likhvar V, Honda Y, Ono M (2011) Relation between temperature and suicide mortality in Japan in the presence of other confounding factors using time-series analysis with a semiparametric approach. Environ Health Prev Med 16:36–43. doi: 10.1007/s12199-010-0163-0

23. Maes M, Meyer F, Thompson P, et al (1994) Synchronized annual rhythms in violent suicide rate, ambient temperature and the light-dark span. Acta Psychiatr Scand 90:391–396. doi: 10.1111/j.1600-0447.1994.tb01612.x

24. Maes M, Scharpe S, Verkerk R, et al (1995) Seasonal variation in plasma L-tryptophan availability in healthy volunteers: Relationships to violent suicide occurrence. Arch Gen Psychiatry 52:937–946. doi: 10.1001/archpsyc.1995.03950230051008

25. Müller H, Biermann T, Renk S, et al (2011) Higher environmental temperature and global radiation are correlated with increasing suicidality—A localized data analysis. Chronobiol Int 28:949–957. doi: 10.3109/07420528.2011.618418

26. Nie Z, Racine JS (2012) The crs package: nonparametric regression splines for continuous and categorical predictors. R J 12:48–56.

27. Page LA, Hajat S, Kovats R (2007) Relationship between daily suicide counts and temperature in England and Wales. Br J Psychiatry 191:106–112. doi: 10.1192/bjp.bp.106.031948

28. Preti A (1998) The influence of climate on suicidal behaviour in Italy. Psychiatry Res 78:9–19. doi: 10.1016/S0165-1781(97)00154-6

29. Preti A (1997) The influence of seasonal change on suicidal behaviour in Italy. J Affect Disord 44:123–130. doi: 10.1016/S0165-0327(97)00035-9

30. Preti A, Lentini G, Maugeri M (2007) Global warming possibly linked to an enhanced risk of suicide: Data from Italy, 1974-2003. J Affect Disord 102:19–25. doi: 10.1016/j.jad.2006.12.003

31. Qi X, Tong S, Hu W (2009) Preliminary spatiotemporal analysis of the association between socio-environmental factors and suicide. Environ Health. doi: 10.1186/1476-069X-8-46

32. R Core Team (2013) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org/

33. Robbins MC, Dewalt BR, Pelto PJ (1972) Climate and behavior: A biocultural study. J Cross-Cult Psychol 3:331–344. doi: 10.1177/002202217200300402

34. Rotton J (1986) Determinism redux: climate and cultural correlates of violence. Environ Behav 18:346–368. doi: 10.1177/0013916586183003

35. Ruuhela R, Hiltunen L, Venäläinen A, et al (2008) Climate impact on suicide rates in Finland from 1971 to 2003. Int J Biometeorol 53:167–175. doi: 10.1007/s00484-008-0200-5

36. Schönbrodt F (2012) Visually weighted regression in R (à la Solomon Hsiang). http://www.nicebread.de/visually-weighted-regression-in-r-a-la-solomon-hsiang/

37. Souêtre E, Wehr TA, Douillet P, Darcourt G (1990) Influence of environmental factors on suicidal behavior. Psychiatry Res 32:253–263. doi: 10.1016/0165-1781(90)90030-9

38. Statistics New Zealand (2013) Subnational population estimates tables. http://www.stats.govt.nz/browse_for_stats/population/estimates_and_projections/subnational-pop-estimates-tables.aspx. Accessed 30 May 2014

39. Törő K, Dunay G, Bartholy J, et al (2009) Relationship between suicidal cases and meteorological conditions. J Forensic Leg Med 16:277–279. doi: 10.1016/j.jflm.2008.12.015

40. Vyssoki B, Praschak-Rieder N, Sonneck G, et al (2012) Effects of sunshine on suicide rates. Compr Psychiatry 53:535–539. doi: 10.1016/j.comppsych.2011.06.003

41. Wang X-F (2010) fANCOVA: Nonparametric Analysis of Covariance.

42. Yang AC, Tsai S-J, Huang NE (2011) Decomposing the association of completed suicide with air pollution, weather, and unemployment data at different time scales. J Affect Disord 129:275–281. doi: 10.1016/j.jad.2010.08.010

43. Yan YY (2000) Geophysical variables and behavior: LXXXXIX. The influence of weather on suicide in Hong Kong. Percept Mot Skills 91:571–577. doi: 10.2466/pms.2000.91.2.571

44. Yip PSF, Chao A, Ho TP (1998) A re-examination of seasonal variation in suicides in Australia and New Zealand. J Affect Disord 47:141–150. doi: 10.1016/S0165-0327(97)00135-3

45. Zung WWK, Green RL (1974) Seasonal variation of suicide and depression. Arch Gen Psychiatry 30:89–91. doi: 10.1001/archpsyc.1974.01760070067010