Published in final edited form as:
Sci Total Environ. 2009 May 1; 407(10): 3421–3424. doi:10.1016/j.scitotenv.2008.12.044.

Cold surge: a sudden and spatially varying threat to health?

Tse-Chuan Yang, Ph.D[1], **Pei-Chih Wu, Ph.D**[2], **Vivian Yi-Ju Chen, Ph.D**[3], and **Huey-Jen Su, ScD.**[4]

[1]The Social Science Research Institute, the Pennsylvania State University, USA

[2]Department of Occupational Safety and Health, Chang Jung Christian University, Taiwan, R.O.C

[3]Department of Statistics, Tamkang University, Taiwan, R.O.C

[4]Department of Environmental and Occupational Health, National Cheng Kung University, Taiwan, R.O.C

Abstract

While cold surge is one of the most conspicuous features of the winter monsoon in East Asia, its impact on human health remains underexplored. Based on the definition by the Central Weather Bureau in Taiwan, we identified four cold surges between 2000 and 2003 and collected the cardiovascular disease mortality data two weeks before and two weeks after these events. We attempted to answer the following research questions: 1) whether the cold surges impose an adverse and immediate effect on cardiovascular mortality; 2) whether the people living in temperate zones have a higher tolerance of extreme temperature drop than do those in the subtropics. With geographic weighting techniques, we not only found that the cardiovascular disease mortality rates increased significantly after the cold surges, but also discovered a spatially varying pattern of tolerance to cold surges. Even within a small study area such as Taiwan, human reaction to severe weather drop differs across space. Needless to say, in the U.S., these findings should be considered in redirecting policy to address populations living in warm places when extreme temperature drops occur.

Keywords

cold surge; spatial non-stationarity; cardiovascular disease mortality

Background

One of the most conspicuous features of the winter monsoon in East Asia is cold surge (Chen, Huang et al. 2004). Siberian highs cause the cold air to flow southward and thus induce cold surges over East Asia (Ding 1990). Although it is well-documented that the surges will bring both severe weather and monsoon rainfall (Cheang 1987; Chen 2002), the immediate impact of cold surges on human health, cardiovascular mortality in particular, remains underexplored.

Correspondence to: Tse-Chuan Yang.

Contact Information: TSE-CHUAN YANG: Corresponding Author. The Social Science Research Institute, The Pennsylvania State University, 803 Oswald Tower, University Park, 16802, USA. (tuy111@psu.edu, TEL: 1-814-865-5553).
PEI-CHIH WU: Dept. of Occupational Safety and Health, Chang Jung Christian University, 396 Chang Jung Rd., Sec. 1, Kway Jen, Tainan 71101, Taiwan, R.O.C. (amb.wu@msa.hinet.net. TEL: 886-6-2752459, FAX: 886-6-2743748).
YI-JU CHEN: Department of Statistics, Tamkang University, 151 Ying-chuan Road, Tamsui, Taipei County, Taiwan 251, R.O.C. (viviyjchen@stat.tku.edu.tw. TEL: 886-2-2621-5656 ext. 3019)
HUEY-JEN SU: Dept. of Environmental and Occupational Health, Medical College, National Cheng Jung University, 138 Sheng-Li Rd., Tainan 70428, Taiwan, R.O.C. (hisu@email.ncku.edu.tw, TEL:886-6-2752459)

Acute temperature drop or exposure to cold can result in direct cardiovascular stress due to the increase in blood viscosity, blood pressure, vasoconstriction, plasma cholesterol and fibrinogen. These hemo-concentration processes may lead to arterial thrombosis and hence trigger rapid death caused by ischemic heart and cerebrovascular diseases (Keatinge, Cloeshaw et al. 1984; Neild, Syndercombe-Court et al. 1994; Imai, Munakata et al. 1996). In Taiwan, approximately 20 percent of the annual total deaths result from cardiovascular diseases (Department of Health in Taiwan 2006).

According to the Central Weather Bureau in Taiwan, cold surges are defined in terms of the following temperature changes: 1) a surface temperature drop within 24 hours that is greater than 8 degrees Celsius, or 2) the lowest temperature in the Taipei metropolitan area registering below 10 degrees Celsius (Central Weather Bureau 2008). We identify four cold surges between 2000 and 2003 and collect the cardiovascular disease mortality data at the township level two weeks before and two weeks after the events (Hendrickson, Vogt, et al 1997). The first issue this report would like to address is whether the cold surges have an adverse and immediate effect on cardiovascular disease mortality. If so, the cardiovascular mortality after the cold surges should be statistically higher than that before the cold waves.

A study in Europe demonstrated that all-cause mortality increased to a greater extent with given drops of temperature in countries with traditionally warm winters (The Eurowinter Group 1997). In addition, cardiovascular disease mortality showed the same pattern in a recent paper (Mercer 2003). These studies suggest that people living in a place with mild winters are less adaptable to cold surges than those in regions with severe winters. Furthermore, we noticed few studies, if any, have focused on subtropical regions. This preliminary analysis will fill this gap. Geographically, northern Taiwan is in a subtropical zone (above latitude 23.5 degrees north) and the middle/southern part of the island is in the tropics. This feature leads us to examine the second empirical question of whether the impact of cold surges on health is stronger in southern and middle Taiwan than it is in the north. Explicitly, we hypothesize that the people living in the north have a higher tolerance to extreme temperature drop (lower mortality ratio) than do those residing in the subtropics.

Methods

To verify these hypotheses, we calculate the death rate per 10,000 capita and the standardized mortality ratio using the following equations:

$$\textit{Death rate}=\frac{\text{Total Death by Cardiovascular Diseases}}{\text{Total Population at Risk}}*10000 \tag{1}$$

$$\textit{Mortality ratio}=\frac{(D^{i}_{\text{after}}/D^{i}_{\text{before}})}{(\sum_{i=1}^{n}D^{i}_{\text{after}}/\sum_{i=1}^{n}D^{i}_{\text{before}})}, \tag{2}$$

where D^{i}_{after} is the total number of deaths after cold surges at township i. D^{i}_{before} is the total number of deaths before cold surges at township i.

Equation (1) and (2) are used to answer the first and second hypotheses, respectively. It should be noted that we are aware of the spatial dependency embedded in our data. Therefore, we employ the approach of a geographical weighting technique to adjust for the non-stationarity across space (Fotheringham, Brunsdon et al. 2002). The principle of

NIH-PA Author Manuscript

NIH-PA Author Manuscript

geographical weighting is to place a kernel around an arbitrary point (*u*,*v*), and computing a weighted proportion *p* of cardiovascular mortality for all of the data located inside the window:

$$p(u, v)=\frac{\sum D_i w_i(u, v)}{\sum w_i(u, v)}, \tag{3}$$

where

D_i denotes the mortality rate at township i and $w_i(u, v)$ is the weight assigned to township i according to the bisquare kernel function:

$$w_i(u, v)=\left[1-\left(\frac{d_i(u, v)}{h}\right)^2\right]^2 \quad \text{if } d_i(u, v) \leq h \text{ ;otherwise } 0, \tag{4}$$

where

d_i (u, v) is the distance between location i and the arbitrary point (*u*,*v*). *h* is a constant called bandwith and has the actual distances between townships. When *h* is great enough to cover all the data points, the local weighting will become the global weighting. The statistical software Geographically Weighted Regression 3.0 will select the bandwith which yields the smallest Akaike Information Criterion (Fotheringham, Brunsdon et al. 2002).

Results

Table 1 demonstrates the auxiliary analytic results. In accordance with the population data from the 2000 Taiwan Census, we can only identify the cold surges occurring from 2000 until 2003. Because the cardiovascular mortality rates before and after cold surges are not independent events for each township, we employed the paired-samples' T-test to investigate whether the mortality rates are significantly different. During this period, the cardiovascular mortality rates elevated invariably after the cold surges (see Panel A). The first two events reached the statistical level at 0.05 and the cumulative mortality rate also echoed this trend. The rates returned to the baseline after three weeks. In addition, as the global warming is evitable, the immediate impacts of cold surges seem to have a decreased trend – the differences in mortality associated with the last three cold surges shrink dramatically. More data need to be collected to further illustrate the pattern.

Panel B shows the geographical variation of mortality ratios on the island. The townships in eastern Taiwan had a mean ratio below 1, indicating that these townships outperformed the national average. One plausible explanation is that the eastern townships are protected by the rugged mountains running between the northern and southern tips of the island. As cold surges come from the northwest, the cold air is impeded by the mountains and hence the impact will be attenuated. As expected, the mean mortality ratio in northern Taiwan is lower than those in the middle and southern townships.

To further investigate the relationships between regions, we first conducted ANOVA to test whether any significant difference exists among the mean mortality ratios. The F-ratio (see Panel C) is 92.063 and significant at the level 0.001, indicating the post hoc range tests and pairwise multiple comparisons should be done. One major finding is reflected in Panel C: There were statistically significant differences in mortality ratio for every pair-wise comparison, regardless of the assumptions imposed on variance. Mortality ratios did vary across space, confirming the geographical variation and non-stationarity. The residents in the southern/middle part of the island showed a lower tolerance (higher mean mortality ratio) to rapid temperature drop or cold surges. We further used geographically weighting skills to cartographically visualize the spatial variation in Figure 1. There were three major clusters of high mortality ratios (the darkest group) and all of them were concentrated in the middle/southern regions of Taiwan. Based on Figure 1, the advantage enjoyed by the eastern township was conspicuous in contrast to other regions.

Discussion and Conclusion

We acknowledge two limitations in this study. First, being an ecological study, the ecological bias should be noted. The findings here should be cautiously interpreted because the expected ecological associations could not completely reflect the effects at the individual level. Because we cannot obtain individual data, the township level is the finest unit available. In addition, this study is designated to be an exploratory study and thus some known or hypothesized determinants of cardiovascular mortality are not included in this study. Although in Taiwan few houses and public facilities are equipped with heating systems, considering the time spent outdoors in cold weather, and the proportion of people wearing hats, gloves and anoraks was proposed to associate the effects of cold surges (The Eurowinter Group 1997; Donaldson, Rintamaki et al. 2001).

This report provides important evidence that 1) cold surges brought not only adverse but also immediate effects on cardiovascular disease mortality and 2) the reaction to severe weather drop differs by region. People living in places with warm winters will suffer more as a result of cold surges than will those inhabiting regions with more severe winter temperatures. Two policy implications can be drawn from our findings. First, the adverse effect of cold exposure on public health is expeditious and should not be underestimated. Although existing weather forecasting system can predict rapid temperature change precisely, more information on the immediately adverse influence on health should be disseminated to the public. Second, the geographic variation shown in this report should redirect policy to pay more attention to the people living in warm places when cold surges attack. Our future work will explore why these phenomena exist and identify key risk factors that explain the geographical variation. In doing so, an empirical basis for the adaption of extreme weather events can be established.

References

Central Weather Bureau. 2008. Online document: http://www.cwb.gov.tw/V5/education/announce/PDFfile/commonsense4.pdf

Cheang, BK. Short- and long-range monsoon prediction in Southeast Asia. In: Fein, JS.; Stephens, PL., editors. Monsoons. John Wiley and Sons; 1987. p. 579-619.

Chen TC. A north Pacific short-wave train during the extreme phases of ENSO. Journal of Climate. 2002; 15:2359–76.

Chen TC, Huang WR, Yoon J. Interannual variation of the East Asian cold surge activity. Journal of Climate. 2004; 17:401–13.

Department of Health, Executive Yuan, Health Statistics in Taiwan. 2006. See http://www.doh.gov.tw/EN2006/DM/DM2.aspx?now_fod_list_no=9377&class_no=390&level_no=2#

Ding Y. Build-up, air mass transformation and propagation of Siberian high and its relations to cold surge in east Asia. Meteorol Atmos Phys. 1990; 44:281–92.

Donaldson GC, Rintamaki H, Naysa S. Outdoor clothing: its relationship to geography, climate, behaviour and cold-related mortality in Europe. International Journal of Biometeorology. 2002; 45:45–51. [PubMed: 11411415]

NIH-PA Author Manuscript

NIH-PA Author Manuscript

Fotheringham, S.; Brunsdon, C.; Charlton, M. Geographically Weighted Regression: The Analysis of Spatially Varying Relationship. John Wiley and Sons; New York: 2002.

Hendrickson LA, Vogt RL, Goebert D, Pon E. Morbidity on Kauai before and after Hurricane Iniki. Preventive Medicine. 1997; 26:711–716. [PubMed: 9327481]

Imai Y, Munakata MI, Tsuji I, et al. Seasonal variation in blood pressure in normotensive women studied by home measurements. Clinical Science. 1996; 90:55–60. [PubMed: 8697706]

Keatinge WR, Cloeshaw SRK, Cortter F, Mattock M, Murphy M, Chelloah R. Increases in platelet and red cell counts, blood viscosity, and arterial pressure during mild sirface cooling: factors in mortality from coronary and cerebral thrombosis in winter. BMJ. 1984; 289:1405–08. [PubMed: 6437575]

Mercer JB. Cold–an underrated risk factor for health. Environmental Research. 2003; 92:8–13. [PubMed: 12706750]

Neild PJ, Syndercombe–Court D, Keatinge WR, Donaldson GC, Mattock M, Caunce M. Cold induced increases on erythrocyte count, plasma cholesterol and plasma fibrinogen of elderly people without a comparable rise in protein C ir factor X. Clinical Science. 1994; 86:43–48. [PubMed: 8306550]

Keatinge WR, Donaldson GC, et al. The Eurowinter Group. Cold exposure and winter mortality from ischaemic heart disease, cerebrovascular disease, respiratory disease, and all causes in warm and cold regions of Europe. Lancet. 1997; 349:1341–1346. [PubMed: 9149695]

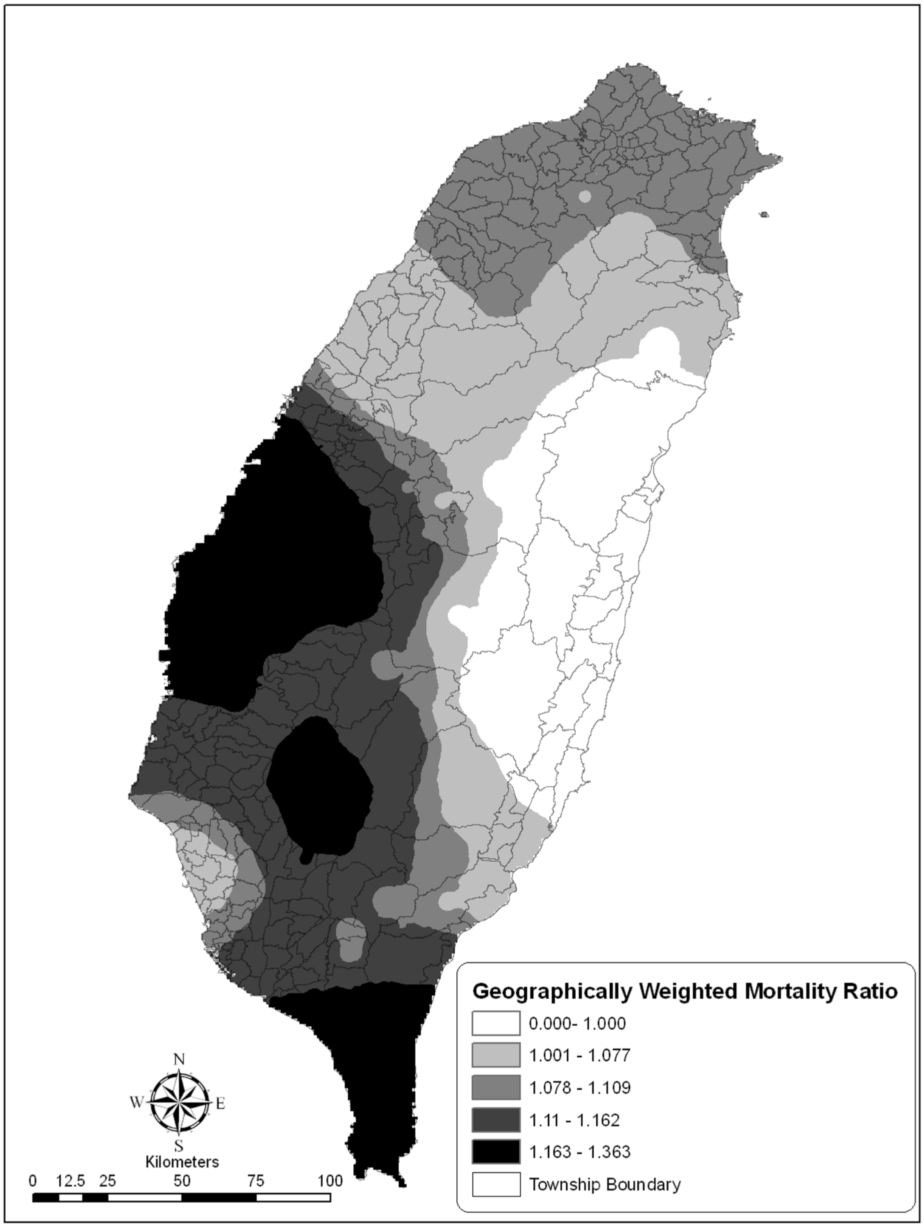

Figure 1.
The distribution of geographically weighted mortality ratio in Taiwan

Table 1

The impact of cold surges on geographically weighted cardiovascular disease mortality from 2000 to 2003.

Panel A	Rates Before	Rates After	Difference	Paired T-statistics	P-Value
Cold Surge 1 (Jan/26/2000)	0.695 (0.717)	0.839 (0.846)	0.144 (1.068)	2.531	0.012
Cold Surge 2 (Dec/24/2001)	0.677 (0.730)	0.827 (0.862)	0.150 (1.115)	2.515	0.012
Cold Surge 3 (Jan/3/2002)	0.772 (0.831)	0.826 (0.828)	0.054 (1.061)	0.950	0.343
Cold Surge 4 (Jan/28/2003)	0.792 (0.855)	0.797 (0.770)	0.005 (1.135)	0.089	0.929
Cumulative	0.734 (0.472)	0.822 (0.538)	0.088 (0.585)	2.826	0.005

Panel B	Mean Mortality Ratio	Minimum	Maximum	S.D.
Northern Taiwan (N=95)	1.083	1.033	1.107	0.018
Middle Taiwan (N=108)	1.173	1.003	1.263	0.056
Southern Taiwan (N=107)	1.136	1.047	1.363	0.059
Eastern Taiwan (N=39)	0.991	0.783	1.248	0.129
Total	1.117	0.783	1.363	0.084

Panel C						
ANOVA	F-Ratio = 92.063	P-value = 0.000				
Comparisons	N v.s M	N v.s S	N v.s E	M v.s S	M v.s E	S v.s E
Mean Difference	−0.089	−0.053	0.092	0.037	0.181	0.144
Equal Variances Assumed[a]	***	***	***	***	***	***
Unequal Variances Assumed[b]	***	***	***	***	***	***

[a] Tukey's honestly significant difference test is used to test the mean difference.

[b] Dunnett's C is used to test the mean difference.

*** p-value < 0.001