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Investigating the relationship between weather and violence in Baltimore, Maryland, USA

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ABSTRACT

Background: It is a common refrain at major urban trauma centers that caseloads increase in the heat of the summer. Several previous studies supported this assertion, finding trauma admissions and crime to correlate positively with temperature. We examined links between weather and violence in Baltimore, MD, through trauma presentation to Johns Hopkins Hospital and crime reports filed with the Baltimore Police Department.

Methods: Crime data were obtained from the Baltimore City Police Department from January 1, 2008 to March 31, 2013. Trauma data were obtained from a prospectively collected registry of all trauma patients presenting to Johns Hopkins Hospital from January 1, 2007 to March 31, 2013. Weather data were obtained from the National Climatic Data Center. Correlation coefficients were calculated and negative binomial regression was used to elucidate the independent associations of weather and temporal variables with the trauma and crime data.

Results: When adjusting for temporal and meteorological factors, maximum daily temperature was positively associated with total trauma, intentional injury, and gunshot wounds presenting to Johns Hopkins Hospital along with total crime, violent crime, and homicides in Baltimore City. Associations of average wind speed, daily precipitation, and daily snowfall with trauma and crime were far weaker and, when significant, nearly universally negative.

Conclusion: Maximum daily temperature is the most important weather factor associated with violence and trauma in our study period and location. Our findings suggest potential implications for hospital staffing to be explored in future studies.

Introduction

It is a common refrain among medical professionals that trauma cases increase during the summer [1,2]. Higher temperatures lead to more activity, more accidents, more confrontations and thus, increased trauma, or so the thinking goes.

The effects of weather on trauma admission have been investigated in the United States at Level I trauma centers in Boston, MA, [1] Louisville, KY, [2] and Minneapolis-St. Paul, MN [3]. These studies each demonstrated a positive linear correlation between increasing daily temperatures and the frequency of trauma presentation. Two of the studies (MN, KY) reported a positive correlation between increasing precipitation and trauma presentation, while the third study (MA) reported a negative correlation between precipitation and trauma. There was also a study from New York City, NY, that found a positive correlation between baseball-bat related trauma and temperature, but did not look at other weather factors [4].

Internationally, reports have been similar. Researchers from the United Kingdom [5] and from Tokyo, Japan [6] reported positive correlations between both temperature and precipitation and trauma. A study from the Netherlands reported that trauma increased with "good" weather [7] Researchers in Seoul, Korea, reported a positive correlation between higher temperatures and all disease presentation, but did not establish linearity or investigate precipitation [8]. One study, however, from Leicester, UK, found no correlations between any meteorological variables and trauma admissions at their hospital [9].

While these studies have demonstrated correlations between temperature and trauma presentation, none specifically investigated trauma due to violence. Studies performed in the US cities of

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Dallas, TX [10] and Durham, NC [11], found strong associations between temperature and violent crime, but these studies were based on police department data and did not investigate trauma presentation.

We sought to elucidate how weather correlates with the occurrence of violent crimes and the utilisation of trauma care services in Baltimore, Maryland, USA, using crime data from the Baltimore City Police Department (BPD) and trauma data from Johns Hopkins Hospital (JHH). Combining these data with meteorological data from nearby Baltimore-Washington International Airport, we examined the hypothesis that an increasing daily temperature is positively correlated with an increase in both violent crime and trauma presentation, while precipitation and snow are negatively correlated with both violent crime and trauma presentation.

Methods

Baltimore crime data were extracted from the Victim Based Crime Data on the Baltimore Police Department Website (https://data.baltimorecity.gov/Public-Safety/BPD-Part-1-Victim-Based-Crime-Data/) for January 1, 2008, through March 31, 2013. Statistical analysis focused on date, type of crime, and weapon use.

After approval was obtained from the Johns Hopkins Medicine Institutional Review Board, patient data was obtained from a prospective trauma registry at Johns Hopkins Hospital for patients presenting from January 1, 2007, through March 31, 2013. The registry contains all cases of adult trauma (age 15 and older) presenting to the Emergency Department at JHH during the study period. The Johns Hopkins Hospital registry uses the Maryland Trauma Registry inclusion criteria [12]. Thus, these records include both admitted and non-admitted patients and include select patients who arrived via emergency medical services, inter-hospital transfer, and personal transportation. Statistical analysis focused on the time of presentation and mechanism of injury. Records that were incomplete for either of these data points were excluded.

Meteorological data pertaining to the Baltimore-Washington International Airport were extracted from the Global Historical Climate Network via the website of the National Climatic Data Center (http://www.ncdc.noaa.gov/cdo-web/datasets). This database contains daily maximum temperature (°C), daily minimum temperature (°C), total daily precipitation (mm), total daily snowfall (mm), and snow depth (mm). All but snow depth were included in the statistical analyses.

Data were compiled and analysed using STATA 12.1 (StataCorp, College Station, TX). Weather variables were linked with the trauma and crime databases based on the date that the injury or crime actually occurred. This was not necessarily the same day that the patient presented to JHH or the crime was reported to the BPD. Correlation coefficients were calculated to establish the relationship between the weather and the numbers and types of traumas or crimes occurring. Multivariable regression was used to elucidate the independent effects of the weather variables on amount and type of crime and trauma. Minimum daily temperature was not used for the regression analysis due to its strong correlation with maximum daily temperature. Temporal effects of month and weekends were also included in this regression analysis. Weekend was defined as 00:00 on Saturday through 23:59 on Sunday. Since the data were overdispersed, negative binomial regression was used for these analyses. These coefficients were then converted to display the incidence rate ratio (IRR) for a 1 unit change in the weather variables. Additionally, relationships between weather and the proportion of shootings among crimes involving a firearm were analysed using a generalised linear model (GLM) with a log-link function; the resulting coefficients were exponentiated and reported as risk ratios (RR).

Results

Baltimore Police Department crime data

A total of 259,095 crimes were reported to the BPD between January 1, 2008 and March 31, 2013, an average of 135 per day. All had complete records for date and type of crime and were included in our study. There were 32,654 violent crimes (12.6% of total crime, 17 per day) and 1159 homicides (0.5% of total crime, 0.6 per day). Violent crime was defined as aggravated assault, rape, shooting, and homicide. There were 929 homicides committed with a firearm. Of the 17,860 crimes where a firearm was involved, 3197 (17.9%) resulted in a shooting or homicide. Daily total crime peaked in July, while daily violent crime peaked in June (Fig. 1A). Daily total crime and daily violent crime both increased with temperature (Fig. 2A).

The daily number of total crimes, violent crimes, and homicides, along with the proportion of gun crimes resulting in a shooting or homicide were all positively correlated with maximum and minimum daily temperatures. Each crime-type except homicide was negatively correlated with average daily wind speed and precipitation. Snowfall was not correlated with crime (Table 1).

In negative binomial regression models controlling for maximum daily temperature, average wind speed, precipitation, snow, month of the year, and day of the week, increased maximum daily temperature was associated with an increase in total crime (IRR = 1.0067, $p < 0.001$) and violent crime (IRR = 1.0128, $p < 0.001$). Precipitation was associated with a decrease in total crime (IRR = 0.9884, $p = 0.001$) and violent crime (IRR = 0.9804, $p = 0.013$). Snow was associated only with a decrease in total crime (IRR = 0.9827, $p < 0.001$). Wind speed was not significantly

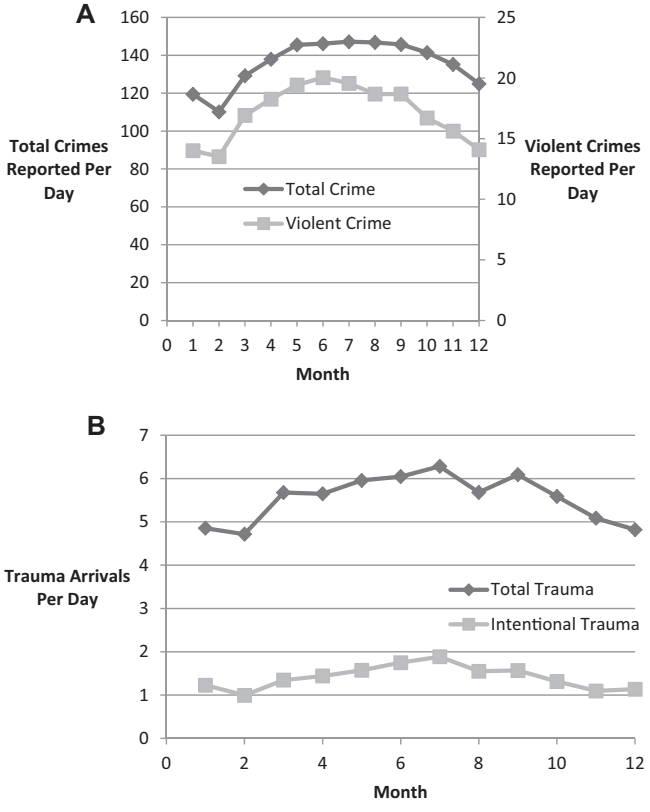

Fig. 1. (A) Average number of daily crimes and violent crimes committed in Baltimore, MD, for each month of the year over a 75 month period. (B) Average number of daily traumas and intentional traumas presenting to Johns Hopkins Hospital for each month of the year over an 87 month period.

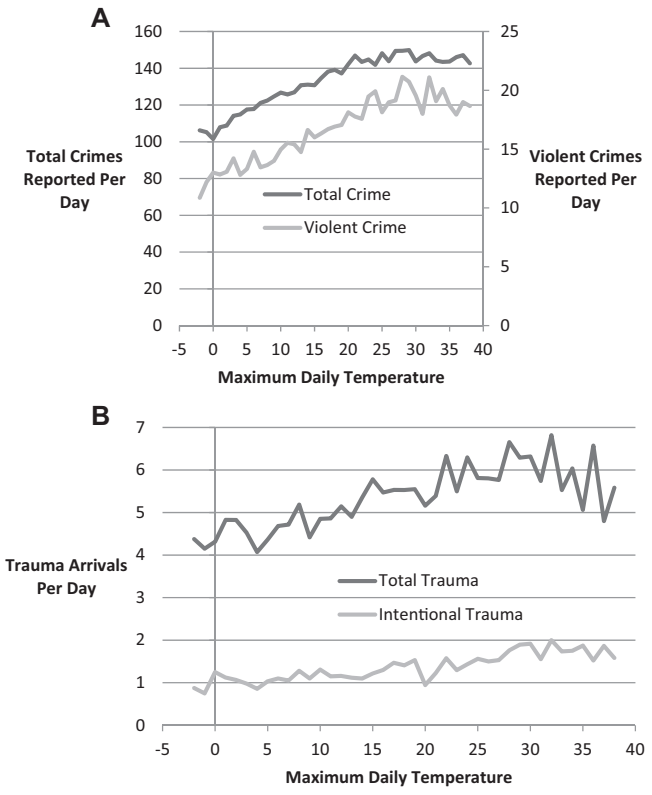

Fig. 2. A. Average number of daily crimes and violent crimes committed in Baltimore, MD, for each maximum daily temperature over a 75 month period. Data are only presented for maximum daily temperatures that occurred 10 or more times in the study period. (B) Average number of daily traumas and intentional traumas presenting to Johns Hopkins Hospital for each maximum daily temperature over an 87 month period. Data are only presented for maximum daily temperatures that occurred 10 or more times in the study period.

Table 2
Negative binomial regression models for prediction of total crime (A), violent crime (B), and homicide (C) and a generalised linear model for the ratio of shootings and firearm homicides to all crimes involving a firearm (D). All corrected for month. IRR = incidence rate ratio. RR = risk ratio.

	A Total crime		
	IRR	*p*-value	95% CI
TMAX	**1.0069**	**<0.001**	**1.0056–1.0081**
AWND	.9989	0.052	.9977–1.0000
PRCP	**.9884**	**0.001**	**.9818–.9949**
SNOW	**.9827**	**<0.001**	**.9772–.9984**
WEEKEND	**.9736**	**<0.001**	**.9614–.9860**
	B Violent crime		
	IRR	*p*-value	95% CI
TMAX	**1.0128**	**<0.001**	**1.0096–1.0160**
AWND	.9972	0.058	.9943–1.0000
PRCP	**.9804**	**0.013**	**.9653–.9958**
SNOW	.9929	0.082	.9850–1.0009
WEEKEND	**1.2289**	**<0.001**	**1.1910–1.2680**
	C Homicide		
	IRR	*p*-value	95% CI
TMAX	1.010	0.122	.9973–1.0228
AWND	.9993	0.898	.9878–1.011
PRCP	.9939	0.823	.9419–1.0488
SNOW	1.0029	0.792	.9813–1.0250
WEEKEND	**1.1909**	**0.008**	**1.0468–1.3548**
	D Ratio of shootings and firearm homicides to all crimes involving a firearm		
	RR	*p*-value	95% CI
TMAX	**1.0124**	**0.028**	**1.0014–1.0236**
TMIN	.9992	0.908	.9867–1.0119
AWND	.9982	0.668	.9903–1.0063
PRCP	**.9522**	**0.036**	**.9095–.9969**
SNOW	.9778	0.243	.9415–1.0154
WEEKEND	**1.126**	**0.003**	**1.0401–1.219**

associated with any of the crime categories studied. Interestingly, none of the weather variables was associated with a change in homicide. Weekends were linked with a decrease in total crime (IRR = 0.9736, $p < 0.001$), but an increase in violent crime (IRR = 1.2289, $p < 0.001$) and an increase in homicide (IRR = 1.1909, $p = 0.008$) (Table 2A–C).

A generalised linear model was also created using the same covariates for the proportion of firearm-involved crimes that resulted in a shooting. Maximum daily temperature (RR = 1.0124, $p = 0.028$) and weekends (RR = 1.1260, $p = 0.003$) were both associated with an increase in the proportion of firearm-related crimes which resulted in a shooting. Precipitation was negatively associated with this proportion (RR = 0.9522, $p = 0.036$), while wind speed and snow had insignificant associations (Table 2D).

To elucidate whether temperature changes were equally important in all seasons and all days of the week, we performed interaction tests between temperature and month and between temperature and day of the week. Both of these were not statistically significant, suggesting that the impacts of temperature change on crime and trauma are not affected by the day of the week or month of the year.

Johns Hopkins Hospital trauma data

A total of 13,629 patients presented to the JHH ED under a trauma classification between January 1, 2007 and March 31, 2013. Of these, 13,398 (98.3%) had complete records and were included in our study, an average of 5.87 patients per day. Of these, there were 5239 (39.1%) traumas due to intentional injury (based on CDC classifications). Daily total trauma and daily intentional trauma both peaked in July during the study period and both also increased with temperature (Fig. 1B and Fig. 2B).

The total number of traumas, the number of traumas due to intentional injury, the total number of traumas due to accidental injury, and the number of gunshot wounds presenting to JHH on a given day all had positive statistically significant correlations with maximum and minimum daily temperatures. Negative

Table 1
Correlation between Baltimore Police Department crime data and weather.

Variable	Total crime		Violent crime		Homicide		Shooting/Firearm	
	R	*p*-value	*R*	*p*-value	*R*	*p*-value	*R*	*p*-value
TMAX	**0.5653**	**<0.0001**	**0.3817**	**<0.0001**	**0.0707**	**0.0020**	**0.2069**	**<0.0001**
TMIN	**0.5330**	**<0.0001**	**0.3460**	**<0.0001**	**0.0755**	**0.0009**	**0.1798**	**<0.0001**
AWND	**−0.2148**	**<0.0001**	**−0.1418**	**<0.0001**	−0.0249	0.2753	**−0.0932**	**0.0001**
PRCP	**−0.0830**	**0.003**	**−0.0608**	**0.0078**	−0.0044	0.8473	**−0.0477**	**0.0368**
SNOW	−0.0266	0.2438	−0.0212	0.3525	−0.0402	0.0782	−0.0094	0.6799

Note: Bold text indicates statistical significance: $p \leq 0.05$.

Table 3
Correlation between trauma presentation at JHH and weather variables.

Variable	Total trauma		Intentional injury		Accidental injury		Gunshot wounds	
	Pearson R	*p*-value	Pearson R	*p*-value	Pearson R	*p*-value	Pearson R	*p*-value
TMAX	**0.1960**	**<0.0001**	**0.1931**	**<0.0001**	**0.0874**	**<0.0001**	**0.1154**	**<0.0001**
TMIN	**0.1698**	**<0.0001**	**0.1687**	**<0.0001**	**0.0749**	**<0.0001**	**0.0918**	**<0.0001**
AWND	**−0.0681**	**0.0011**	**−0.0708**	**0.0007**	−0.0317	0.1304	**−0.0614**	**0.0033**
PRCP	−0.0241	0.2490	−0.0293	0.1611	0.0193	0.3574	−0.0356	0.0894
SNOW	−0.0246	0.2399	**−0.0446**	**0.0332**	0.0064	0.7612	0.0101	0.6281

Table 4
Negative binomial regression model for prediction of total trauma (A), trauma from intentional injury (B), trauma from accidental injury (C), and gunshot wounds (D) presenting to JHH. All corrected for month. IRR = incidence rate ratio.

	A Total trauma		
	IRR	*p*-value	95% CI
TMAX	**1.0079**	**<0.001**	**1.0039–1.0119**
AWND	.9986	0.482	.9947–1.0025
SNOW	.9883	0.191	.9709–1.0059
PRCP	.9910	0.405	.9700–1.0123
WEEKEND	**1.2700**	**<0.001**	**1.218–1.323**
	B Intentional trauma		
	IRR	*p*-value	95% CI
TMAX	**1.0155**	**<0.001**	**1.0075–1.0235**
AWND	.9967	0.396	.9891–1.0043
SNOW	.9578	0.119	.9072–1.0112
PRCP	.9800	0.376	.9371–1.0248
WEEKEND	**1.4206**	**<0.001**	**1.310–1.540**
	C Accidental trauma		
	IRR	*p*-value	95% CI
TMAX	1.0026	0.320	.9974–1.0079
AWND	.9984	0.552	.9932–1.0037
SNOW	.9901	0.339	.9700–1.0105
PRCP	1.0061	0.713	.9742–1.0389
WEEKEND	**1.1500**	**<0.001**	**1.0890–1.2143**
	D Gunshot wounds		
	IRR	*p*-value	95% CI
TMAX	**1.0165**	**0.008**	**1.0042–1.0289**
AWND	.9906	0.131	.9786–1.0028
SNOW	.9173	0.063	.8374–1.0048
PRCP	.9533	0.180	.8888–1.0224
WEEKEND	**1.2558**	**0.001**	**1.1010–1.4324**

correlations were found between increased average wind speed and each of the trauma categories except accidental trauma. Increased snow was negatively correlated with intentional injury, but not total trauma, accidental injury, or gunshot wounds. Precipitation was not correlated with any of the trauma categories (Table 3).

In negative binomial regression models controlling for maximum daily temperature, average wind speed, precipitation, snow and month of the year, maximum daily temperature was the only weather covariate significantly associated with increased trauma volume (IRR 1.0079, $p < 0.001$), intentional trauma volume (IRR 1.0155, $p < 0.001$), and gunshot wounds (1.0165, $p = 0.008$) (Table 4A, B and D). Accidental trauma was not significantly associated with any of the weather variables (Table 4C). Weekends were associated with an increase in all trauma (IRR = 1.2700, $p < 0.001$), intentional injury (IRR = 1.4206, $p < 0.001$), accidental trauma (IRR = 1.1500, $p < 0.001$) and gunshot wounds (IRR = 1.2558, $p < 0.001$).

Discussion

When correcting for weather and temporal factors in negative binomial regression models, increasing maximum daily temperature is associated with increases in total crime and violent crime, while precipitation is associated with decreases in both of these factors. This correlates with previous reports [10]. This finding makes intuitive sense as potential criminals and potential victims are more likely to be outside and interacting in favourable weather conditions, allowing for greater criminal opportunity.

Our data, however, do show that temperature and precipitation have a greater association with violent crime than with overall crime, as evidenced by the disparity in incidence rate ratios. Similarly, temperature is associated with an increased ratio of shootings to firearm related crimes and precipitation is associated with a decrease in this ratio. This suggests that not only does violence increase with temperature and decrease with precipitation, but also those potentially violent situations are more likely to escalate to violence with increasing temperature and less likely to escalate with increasing precipitation.

It is interesting that homicide is not independently associated with any of the weather variables in our dataset. This may be an issue of sample size, but may also have to do with the fact that homicide is more likely to be premeditated than other crime. Thus, we would expect it to be less likely an opportunistic occurrence than overall crime, violent crime, or escalation of an armed interaction, and thus less likely to be affected by the weather.

In negative binomial regression models looking at trauma presentation to Johns Hopkins Hospital, maximum daily temperature was the only weather factor independently associated with total trauma, intentional trauma, and gunshot wounds. The association between temperature and trauma corresponds with previously published reports [1–8]. The finding that precipitation is not associated with trauma in our dataset, however, conflicts with most of the previously published reports [1–3,5–7]. Interestingly, maximum daily temperature was not independently associated with accidental trauma, suggesting that the increase in overall trauma with increasing temperature is due entirely to the increase in intentional trauma. This finding, that the increase in intentional trauma is responsible for the increase in overall trauma with increasing temperature, is novel. It is worth noting, however, that the proportion of trauma due to intentional injury at our institution (39.1%) appears to be higher than findings from other reports, which may be related to differences in case-mix specific to our institution. By comparison, another study, using the American College of Surgeons' National Trauma Data Bank from 2001 to 2006, found that only 11.1% of severe trauma in their dataset was due to intentional injury [13].

Wind speed did not have a significant independent association with any of the crime or trauma variables studied, which corresponds with earlier studies [1,2,14]. Snowfall also had no significant independent association with any of the crime or trauma variables except total crime. This finding, that snowfall decreases total crime but does not affect violent crime or trauma, is novel.

Weekends were associated with an increase in violent crime, homicide, and all categories of trauma, which is consistent with previous studies [15,16]. They were, however, associated with a decrease in total crime. The effect of the weekend versus non-weekend is equivalent to a −4 °C change in temperature for total

crime and a +17 °C change in temperature for violent crime. For total trauma, the weekend is the equivalent of a +30 °C change. For intentional trauma, the weekend is the equivalent of a +23 °C change. And for gunshot wounds presenting to JHH, the weekend is the equivalent of a +14 °C change. Given that temperatures rarely change as drastically as many of these equivalences within a short period of time, weekends appear to be a more robust predictor of trauma and violent crime than temperature change on a day to day basis.

The demonstrated associations of weekend and temperature with violence in Baltimore may suggest possible implications for trauma staffing. However, despite an increase in trauma and decrease in staffing on weekends, a single center study found no weekend-related worsening of outcomes [16]. Similar studies are needed to further address whether it might be beneficial to alter hospital staffing in response to meteorological trends. Follow-up work should also consider whether the impact of temperature on violence is augmented or blunted by consistently high and low temperatures and also whether sudden changes in temperature have a more drastic effect on the incidence of violence.

Conclusion

Maximum daily temperature appears to be the most important weather factor associated with trauma due to violence in Baltimore, MD. While our findings characterise a single city, the issues of crime and violence delineated in this report are common to many major urban areas throughout the United States and around the world. Future studies should investigate how patient outcomes are affected by disparate weather conditions, which may provide useful information to guide hospital staffing.

Conflict of interest

None declared.

References

[1] Bhattacharyya T, Millham FH. Relationship between weather and seasonal factors and trauma admission volume at a Level 1 trauma center. J Trauma 2001;51:118–22.
[2] Rising WR, O'Daniel JA, Roberts CS. Correlating weather and trauma admissions at a level 1 trauma center. J Trauma 2006;60:1096–100.
[3] Friede KA, Osborne MC, Erickson DJ, Roesler JS, Azam A, Croston JK, et al. Predicting trauma admissions: the effect of weather, weekday, and other variables. Minn Med 2009;92:47–9.
[4] Bernstein SL, Rennie WP, Alagappan K. Impact of Yankee Stadium Bat Day on blunt trauma in northern New York City. Ann Emerg Med 1994;23:555–9.
[5] Parsons N, Odumenya M, Edwards A, Lecky F, Pattison G. Modeling the effects of the weather on admissions to UK trauma units: a cross-sectional study. Emerg Med J 2011;28:851–5.
[6] Abe T, Tokuda Y, Ohde S, Ishimatsu S, Nakamura T, Birrer RB. The influence of meteorological factors on the occurrence of trauma and motor vehicle collisions in Tokyo. Emerg Med J 2008;25:769–72.
[7] Stomp W, Fidler V, ten Duis HJ, Nijsten MW. Relation of the weather and the lunar cycle with the incidence of trauma in the Groningen region over a 36 year period. J Trauma 2009;67:1103–8.
[8] Choi SH, Lee SW, Hong YS, Kim SJ, Kim NH. Effects of atmospheric temperature and humidity on outbreak of diseases. Emerg Med Aust 2007;19:501–8.
[9] Atherton WG, Harper WM, Abrams KR. A year's trauma admissions and the effect of the weather. Injury 2005;36:40–6.
[10] Cook MR, Emick D, Foley C, Beatty A, McCormick C, Shapiro M. Daily temperature predicts assault and may allow more efficient policing. Am Surg 2012;78:E194–5.
[11] Gamble JL, Hess JJ. Temperature and violent crime in Dallas, Texas: relationships and implications of climate change. West J Emerg Med 2012;13:239–46.
[12] Gertner M. Maryland State Trauma Registry Data Dictionary for Adult Patients [Internet]. Baltimore: Maryland Institute for Emergency Medical Services Systems [updated 2011 July 11; cited 2015 May 19]. Available from: http://www.miemss.org/home/Portals/0/Docs/OtherPDFs/Maryland_Trauma_Registry_Data_Dictionary.pdf.
[13] Bennett KM, Vaslef SN, Shapiro ML, Brooks KR, Scarborough JE. Does intent matter? The medical and societal burden of self-inflicted injury. J Trauma 2009;67:841–7.
[14] O'Connor ZJ, Helmer SD, Yates CL, Ward JG, Khandelwal A, Haan JM. An evaluation of the effect of wind speed on trauma admissions and injury severity at a Midwest level 1 trauma center. Am Surg 2012;78:614–6.
[15] Watkins CJ, Feingold PL, Hashimoto B, Johnson LS, Dente CJ. Nocturnal violent implications for resident trauma operative experiences. Am Surg 2012;78:657–62.
[16] Carr BG, Jenkins P, Branas C, Wiebe DJ, Kim P, Schwab CW, et al. Does the trauma system protect against the weekend effect? J Trauma 2010;69:1042–8.

Glossary

TMAX: maximum daily temperature (°C)
TMIN: minimum daily temperature (°C)
AWND: average daily wind speed (0.1 m/s)
PRCP: total daily precipitation (mm)
SNOW: total daily snowfall (mm)