Associations between temperature and crime in New South Wales, Australia

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Table of Contents

List of Figures

List of Tables

List of Acronyms and Abbreviations

ABS: Australian Bureau of Statistics

AICc: Akaike Information Criterion, corrected

AUD: Australian dollar

BOCSAR: Bureau of Crime Statistics and Research [NSW]

BOM: Bureau of Meteorology [Australia]

CI: Confidence Interval

GSR: Greater Sydney Region

GWR: Geographically Weighted Regression

LGA: Local Government Area

NSW: New South Wales

OLS: Ordinary Least Squares

SEIFA: Socio-Economic Indexes for Areas

Statement of Originality

This work has not previously been submitted for a degree or diploma in any university. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is made in the thesis itself.

The research presented in this thesis received ethics approval from the Macquarie University Human Ethics Committee; Protocol Number 5201700382.

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Signature

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Date

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I would firstly like to thank my primary thesis supervisor, Associate Professor Paul Beggs, Department of Environmental Sciences, Faculty of Science and Engineering at Macquarie University. Paul has been the perfect blend of knowledge, experience and generosity. Also to my supervisor Dr Petra Graham who makes statistics (almost) enjoyable!

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Finally, to my delightful son Eden, who patiently waited to be born until after the draft thesis was done.

Abstract

This study investigates the relationship between temperature and crime in New South Wales (NSW), Australia. Time series and logistic models were applied to an 11-year dataset of incidents of assault, theft, and fraud, as well as spatial mapping and modelling of assault. Results suggested that assault and theft counts were significantly higher in summer than winter (18 and 6%, respectively), while fraud counts were not significantly different. Using maximum monthly temperature, results indicated that for every 10°C increase in temperature, average monthly assaults increased by 22%, and thefts by 3.5%, while again, the relationship for fraud was not significant. Modelling daily average counts revealed similar results. The study also found that for every 10ºC increase in temperature, a violent crime was 14 to 16 times more likely than a nonviolent. Spatially, 96% of Local Government Areas (LGAs) in NSW had a higher summer assault rate than winter, and LGAs experienced significantly differing responses. The findings of this study provide an empirical foundation for understanding crime-temperature relationships, which may support better predictions of criminal behaviour and allocation of police and health resources. Establishment of such relationships may also be useful for understanding how crime may change in a warming climate.

1. Introduction

For now, these hot days, is the mad blood stirring…

William Shakespeare, Romeo and Juliet, Act 3, Scene 1

The relationship between temperature and deviant behaviour is embedded in the English language, with phrases such as 'hot headed', 'hot under the collar' and a 'simmering anger' commonly referring to feelings of anger or aggression. Studies have found a correlation between warmer temperatures and aggressive behaviour and/or crime at temporal scales ranging from hour to millennium, and spatial scales from buildings to the globe (Anderson et al., 2000; Cohen & Krueger, 2016; Hsiang & Burke, 2014; Michel et al., 2016; Ranson, 2014; Rotton & Cohn, 2000b).

To date, almost all studies on the crime-temperature relationship have drawn on data from the Northern Hemisphere, with only one notable study within Australian conditions (Auliciems & DiBartolo, 1995). However, crime results in significant cost to the Australia economy, and the climate of New South Wales (NSW) is experiencing record high temperatures and projected to continue. Therefore, a greater understanding into the crime-temperature relationship in Australia much needed.

Studies have used a variety of methods including temporal (over time), spatial (how relationships differ geographically) and experimental (within a laboratory or controlled environment). Temporal relationships between aggressive crimes (e.g., assault, homicide) and hot temperatures are the most frequently studied, with most finding that aggressive crime rates are higher in summer (Anderson et al., 2000; Breetzke & Cohn, 2012; Cohn, 1990). The relationship between crime and temperature has been explained through warmer temperatures creating physical discomfort and hence aggression (Anderson, 1989; Tiihonen et al., 2017). However, there are factors beyond temperature that have been proposed, such as being outside and socialising more during summer months, leaving windows open, consuming alcohol, longer daylight hours and cultural values (Anderson et al., 2000; Bell, 1992; Cohen & Felson, 1979; Rinderu et al., 2018).

Understanding the relationship between heat and crime in Australia may enable better predictions of criminal behaviour, and hence improve allocations of police and health resources, as well as development of policies and programs to reduce crime. Establishment of such relationships may also be useful for understanding how crime may change in a warming climate.

1.1 The climate of NSW

Australia is renowned for being a land of extremes, with heatwaves common. However, even by Australian standards, the heatwaves of February 2017 were remarkable, breaking temperature records in many places across the country (Figure 1.1) as well as records for consecutive days of extreme temperatures (Bureau of Meteorology, 2017).

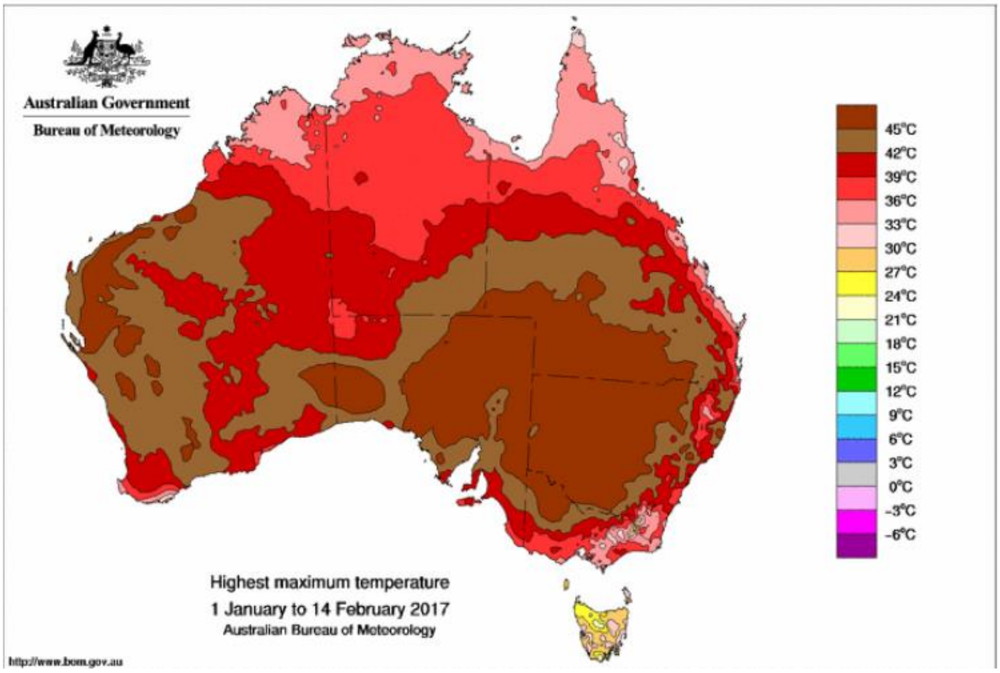

Figure 1.1: Highest maximum temperature observed from 1 January to 14 February 2017 (BOM, 2017)

Understanding the relationship between heat and crime becomes more pressing under a climate that is warming. The NSW Office of Environment and Heritage project an increase in maximum temperatures of 1.8 - 2.6^{o}C by 2070 for NSW. Minimum temperatures are also projected to increase in the range of 1.4 - 2.6°C by 2070 (NSW Office of Environment and Heritage, 2013).

1.2 The economic and social impacts of crime

Crime generates substantial costs to societies at individual, community, and national levels. Table 1.1 shows the recorded counts of crime for Australia in 2011. Incidents of theft and fraud are the most commonly reported crimes nationally. However, when calculating crime estimates, the Australian Institute of Criminology uses a ‘multiplier estimate’, which corrects for crimes that are not well-captured in official administrative records. Some crimes have very low or no multipliers, such as homicide and motor vehicle theft which are almost always recorded. However, for assault, the multiplier is 6.9, and for sexual assault it is 11.3, which indicates the actual number of assaults to be much higher than that recorded (Smith et al., 2014).

Table 1.1: Reported counts of crime and multiplier estimates, Australia, 2011. Adapted from Smith et al. (2014)

Crime type*	Reported crimes	Multiplier estimate	Estimated number of crimes
Criminal damage	249,220	5.9	1,470,398
Shop theft	80,625	16.1	1,298,063
Assault	169,903	6.9	1,172,333
Fraud	97,611	2.6	1,047,185
Other theft	269,000	3.0	807,117
Burglary	218,193	3.5	753,280
Theft from vehicles	168,666	2.3	379,200
Sexual assault	17,592	11.3	198,109
Robbery	13,617	6.3	72,765
Theft of vehicles	55,382	1.2	65,600
Arson	14,975	3.0	44,925
Homicide	463 + 185 attempted	1.0	463 + 185 attempted

* Crime types are ordered by their estimated numbers. No data on drug offences are presented.

An assessment from the Australian Institute of Criminology suggested that crime costs the Australian economy $47.6 billion (AUD) per year, which is 3.4% of gross domestic product (Smith et al., 2014). Forty percent of this cost is from fraud, while property crimes (including theft, burglary, and arson) contribute 30%. Crimes against the person (including assault and homicide) cost around 14% (Figure 1.2).

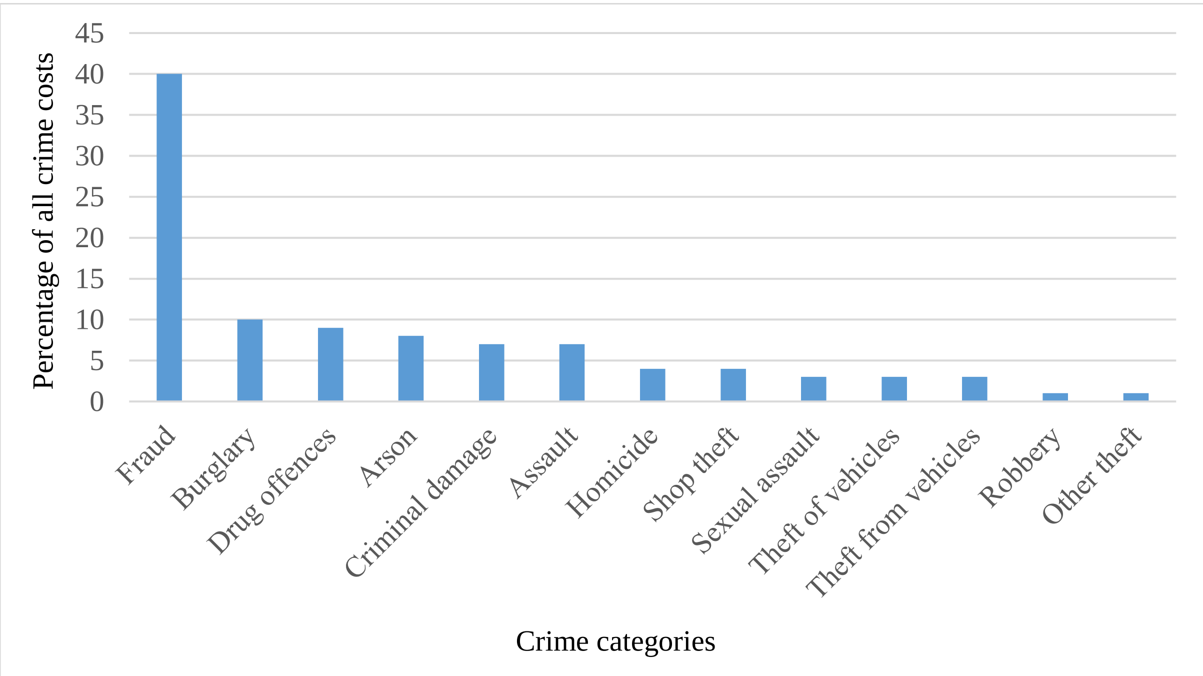

Figure 1.2: Crime categories as a proportion of total costs for Australia, 2005. Modified from Rollings (2008)

The cost per incident of crime is not equal across crime types. For example, shoplifting accounts for over 60% of crimes (when excluding arson, drug offences and fraud), but it accounts for only 9% of the national costs. Violent crime including assault, homicide, and sexual assault is only 8.2% of recorded incidents but accounts for 33% of the costs (Figure 1.3).

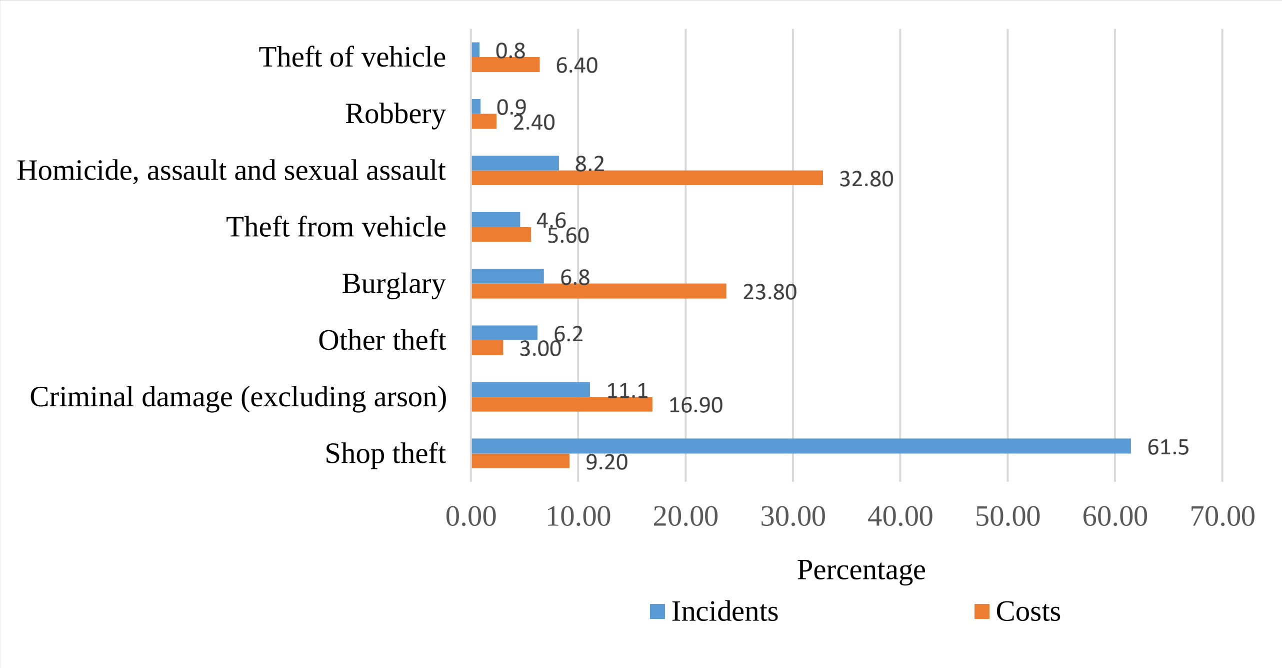

Figure 1.3: Volume and cost of crime in Australia, 2005 (excluding arson, fraud and drug offences). Adapted from Rollings (2008)

Crime also has indirect economic and social costs to victims, their networks, witnesses and even the perpetrators. These costs may be physical pain and suffering, decreased quality of life and psychological distress and the associated costs borne from that. Currently there is little data in Australia with which to estimate intangible losses for crimes against an individual, and this is especially true for violent crimes such as assault and sexual assault (Rollings, 2008).

1.3 Project aims

This study aims to assess relationships between temperature and common offences within New South Wales through an empirical and quantitative study that includes both temporal and spatial modelling. Specifically, it aims to:

- Model the seasonal relationship for the most common offences of assault, theft and fraud using monthly offence counts;
- Model the relationship between maximum monthly temperature and monthly offence counts;
- Model the relationship between maximum daily temperature and daily count of offences, controlling for holidays and weekends;

- Investigate whether temperature influences the odds of a violent versus a nonviolent offence in a logistic regression model, and;
- Model and map spatial differences in assault and temperature relationships.

The results of the study will be discussed in the context of current theories as to why temperature and crime may be related, and how these theories could apply to Australia. This study is novel because it is one of the first known investigations of the crime-temperature relationship within the Australian climate, and is one of very few studies from the Southern Hemisphere. Recommendations from the study will be of value to stakeholders within justice and health services.

1.4 Thesis structure

Chapter 1 has provided a brief introduction to the thesis including the rationale and aims. Chapter 2 presents a literature review on studies that address the heat and crime or aggression relationships. Chapter 3 is a manuscript prepared for submission to the Journal of Environment and Behavior and presents the methods, results, discussion and conclusion of the research, as well as a brief introduction and review of literature. Finally, Chapter 4 draws the thesis together by presenting the overall conclusions, limitations to the study and how this research could be applied and expanded.

2. Literature Review

This chapter presents a review of research to date that investigated the relationship between crime and temperature. A table summarising key studies that used temperature as a predictor of crime/crime proxy is shown in Appendix 1.

2.1 Studies on heat and crime

Philosophers, social geographers and others began discussing the concept of heat and crime around the mid-18th century. French lawyer Montesquiedeu (1748) noted on his travels:

'You will find in the northern climates peoples who have few vices, enough virtues, and much sincerity and frankness. As you move toward the countries of the south, you will believe you have moved away from morality itself; the liveliest passions will increase crime' (Montesquiedeu, 1989).

By the 19th century, empirical studies began to arise, such as that by Quetelet (1833) who analysed temperature and violent crime in the USA and proposed that high temperatures incite people's passions and drive them to violence, raising robbery and assault rates. From the 1950s onwards, studies emerged looking at a range of temperatures (from extreme heat to extreme cold) as well as other climatic factors including humidity, snow, rain, wind, light, fog, and barometric pressure, and other factors such as pollution. Studies assessed recorded crime rates, or crime proxies such as police calls and hospital admissions as well as cognitive indicators of aggressive behaviour.

The majority of studies to date have used three, not mutually exclusive, methodologies: temporal, spatial, and/or experimental.

2.2 Temporal studies

Temporal studies examine the relationship between temperature and crime of a region(s) over time. They have investigated a range of geographical regions (e.g., countries, states and cities) as well as time scales (e.g., years, seasons, months, days and hours). Analyses at different temporal scales are important because different (thought related) things can be learnt from each, with, for example, monthly analysis relating to the seasonal cycle and daily analysis relating to weather fluctuations. The most common offence investigated by temporal studies has been aggressive crimes, and the results are largely consistent. Overall, studies have found that assault rates are higher in summer months than during the rest of the year, across a range of Northern Hemisphere countries (e.g., France, Germany, United States) as well as eras (e.g., 19th and 20th centuries) (Anderson et al., 2000; Burke et al., 2015; Hsiang & Burke, 2014; Ranson, 2014).

Anderson et al. (2000) conducted a comprehensive review of seven large datasets in the Northern Hemisphere and found that across all studies, warmer months had a higher monthly assault rate, in some instances, 40% higher in the hotter months than in colder months (Figure 2.1).

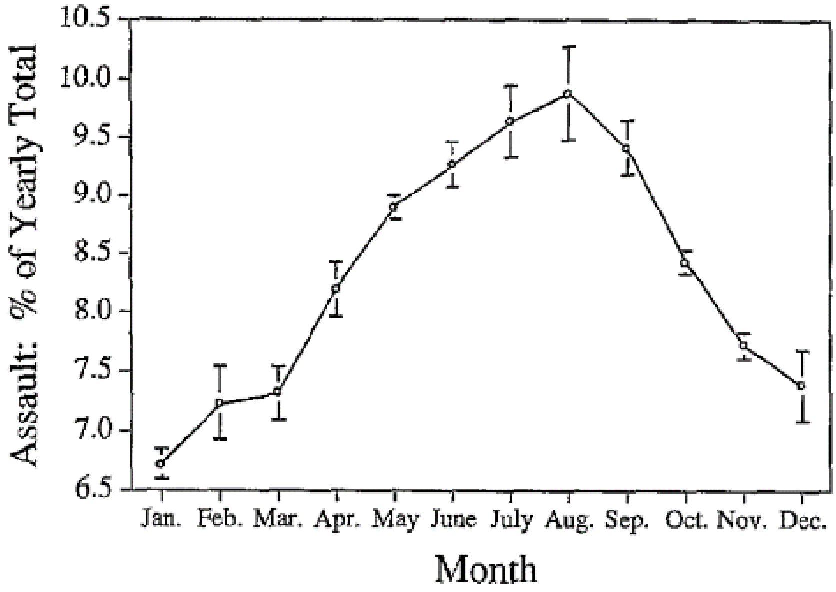

Figure 2.1: Monthly distribution of assaults with standard error bars, averaged across seven Northern Hemisphere datasets. Reprinted from Anderson et al. (2000), page 67

Another extensive temporal study was by Hsiang et al. (2013) who synthesised 60 primary studies on climate and human conflict, including interpersonal violence but also intergroup violence, political instability and civilisation collapse. The study included 45 datasets over a period of over 10,000 years, covering all major world regions. The synthesis controlled for differences in geographical areas as well as effect of time (using day of the week). The study found that climatic influences on modern conflict are both substantial and highly statistically significant. Each 1 standard deviation increase in warmer temperatures increased the frequency of interpersonal violence by 4% (median estimates). Within the USA, Ranson (2014) assessed weather and crime data for 2997 counties, finding temperature had a strong effect on a range of criminal behaviours including rape, assault, vehicle theft and robbery (Figure 2.2).

Temporal studies have also looked at 'irregular' temperature variations by analysing crime at the weekly, daily, or even hourly scale. For example, Jacob et al. (2007) used regression to model weekly data across 116 jurisdictions in the USA over a 6 year period. They found that an approximate 6°C increase in weekly temperature was associated with a 5% increase in violent crime. A novel daily temperature study was that by Larrick et al. (2011) who analysed data from 60,000 major league baseball games to test if higher temperatures increased the likelihood that pitchers respond in a more aggressive way. Controlling for a range of factors, the probability that a pitcher acted aggressively increased sharply at high temperatures (Figure 2.3).

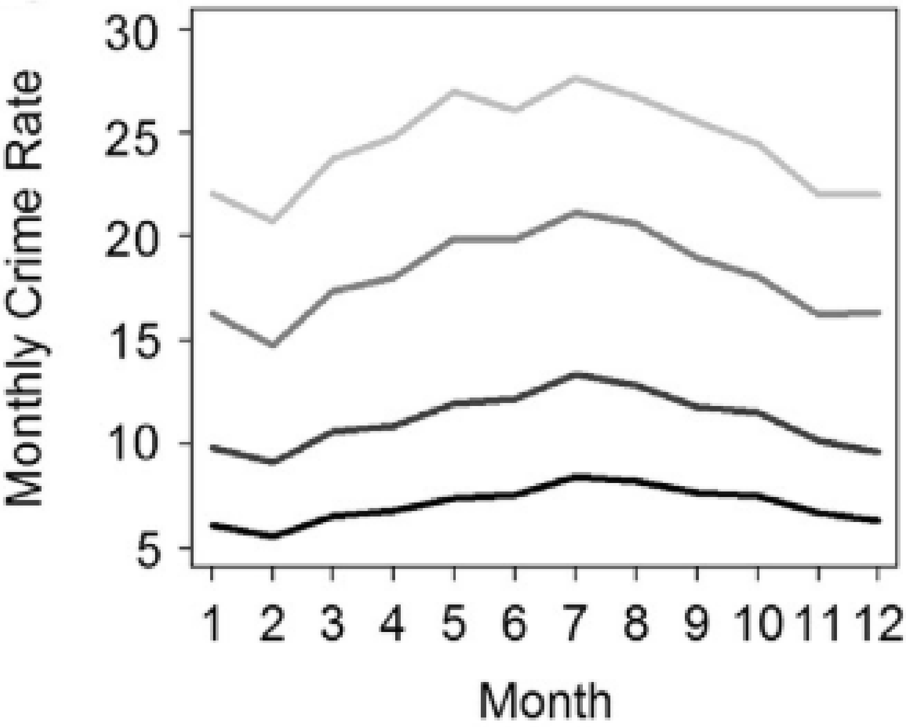

Figure 2.2: Monthly aggravated assault rate (per 100,000 persons) at four temperature ranges across USA counties. The lines, from bottom to top; 12°C or lower, 13-18°C, 19-22°C, 23°C or higher. The months on the x axis are 1 for January through to 12 for December. Reprinted from Ranson (2014), page 281

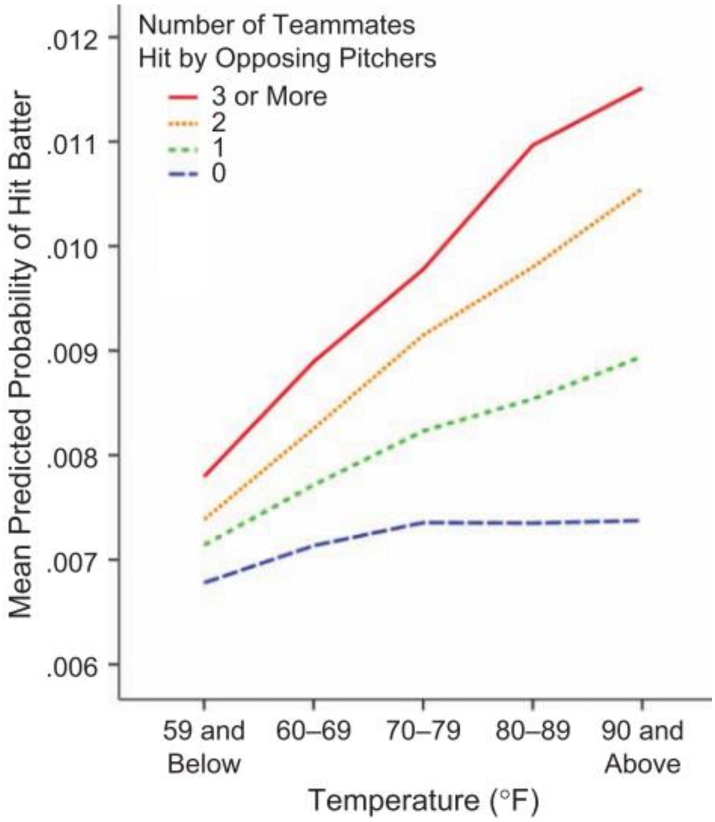

Figure 2.3: Predicted probability of a batter being hit by a pitcher as a function of temperature. 1952-2009, USA. Reprinted Larrick et al. (2011), page 426

2.3 Spatial studies

Spatial studies compare how crime or crime proxies change over space. They may investigate geographic regions (e.g., countries, states, cities, or sub-city areas) that are similar in many respects but differ in climate. For example, Lester (1986) compared homicide rates of 45 metropolitan areas in the USA, finding that rates varied gradually, rather than abruptly, with latitude. Ranson (2014) expanded his USA temporal study to investigate monthly crime and weather data. The study found a striking relationship between monthly weather patterns and crime rates, with hotter temperatures being significantly associated with an increase in a variety of offences.

A weakness in comparing regions is that there are many ways in which populations and societies differ from one another (e.g., culture, history), many of them unobserved or hard to measure. Studies have tried to address this through applying controlling factors: for example, Mares (2013) controlled for income; Horrocks and Menclova (2011) controlled for population and unemployment; while Ranson (2014) used a socio-economic metric that included race, gender, age and town type (e.g., rural or urban).

At a finer scale, Brunsdon et al. (2009) looked at crime rates of an anonymous urban area in the UK, using geographical co-ordinates of police calls within a city against hourly weather data. The study found that both temperature and humidity exert significant effects on the spatial patterning of incidents of disorder and disturbances. However, other environmental factors such as rainfall and wind did not exert such effects. Figure 2.4 shows summer months (temperatures increasing from lower right to upper left panel), with greater proportion of incidents occurring outside the city centre. This was seen also during the warmer winter months (not shown).

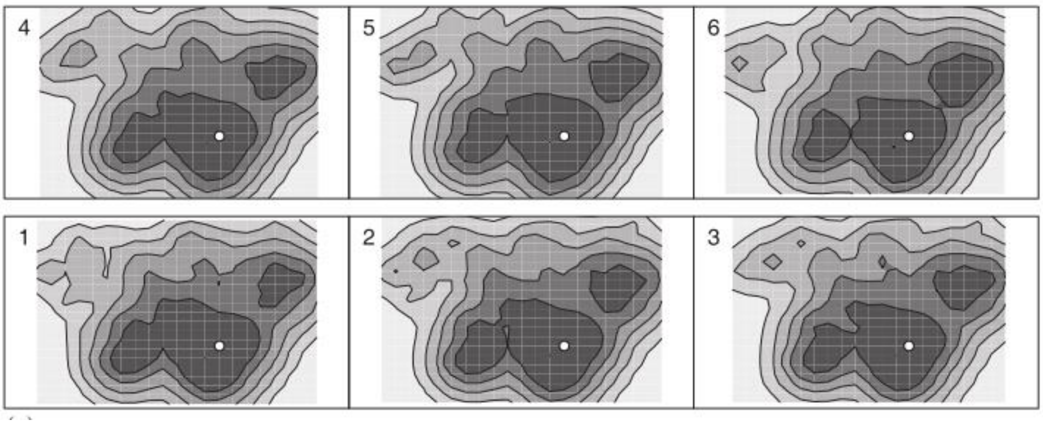

Figure 2.4: Comaps of the distribution of police call outs in summer months for an unidentified urban UK town over a 2 year period. The white dot indicates the central business district, while the panels (1-6) represent subsets of the range from minimum (2°C) to maximum (32°C) temperature differences. Dark grey represents the highest distribution of call outs. Each panel represents a 20km wide region. Reprinted from Brunsdon et al. (2009), page 920

Several studies have combined both spatial and temporal methodologies. For example, Butke and Sheridan (2010) investigated the relationship between weather and aggressive crime in Cleveland, Ohio, to find that, aggressive crime generally increased linearly as temperature increased. They then performed sub-city assessments and found that spatial patterns of crime were minimally influenced by hotter weather (Figure 2.5).

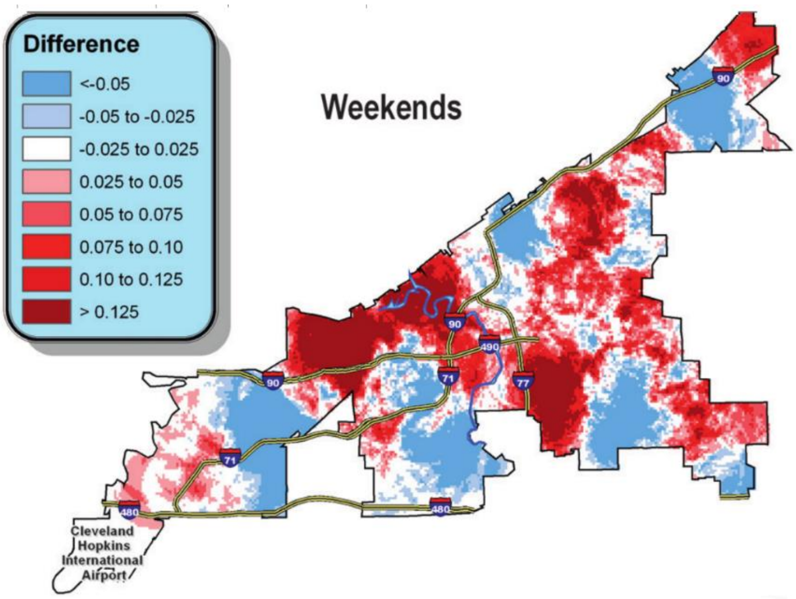

Figure 2.5: Mean difference in crime counts (hotter minus colder conditions) for all aggressive crimes on weekends, 1999-2004, Cleveland, Ohio. Reprinted from Butke and Sheridan (2010), page 136

2.4 Experimental studies

A third method to investigate the aggression-temperature relationship is via experimental studies, performed under controlled conditions. These studies tend to either assess the physiological impacts of heat and aggression, or assess the corresponding behaviour.

Studies that look at physiological impacts of heat on aggression tend to conclude that some neural and hormonal systems impacted by heat are linked to aggression. A review of studies on temperature and hormonal response can be found in Simister and Cooper (2005). For example, thermoregulation, the process that the body undergoes to maintain correct body temperature in response to uncomfortable temperatures has been linked to emotion. The amygdala, hypothalamus, and hippocampus are important brain centres for thermoregulation, as well as the release of both hormones and neurotransmitters related to aggression (Anderson & Anderson, 1998). The amygdala, known as the emotional controller or the 'animal brain', has neurons that are also responsible for changes in heart rate and blood pressure, which can vary with ambient temperature (Anderson & Anderson, 1998; LeDoux, 1993). Testosterone production is influenced by the process of the body sweating, and has been linked to aggressive behaviour in both men and women (Blanchard & Blanchard, 1984).

Experimental studies have also assessed the behaviour that results from participants being subject to temperature variations. Baron and Bell (1976) conducted two experiments to examine the influence of ambient temperature upon physical aggression. In one, male subjects were given the opportunity to give electric shocks, finding that high ambient temperatures (33-35°C) as well as moderate temperatures (28-29°C) facilitated aggression. The second experiment used the same methodology but administered a cooling drink to participants, which was found to reduce aggression. A renowned study done by Kenrick and MacFarlane (1986) assessed aggressive car horn use. An investigator remained stationary at a green traffic light in temperatures ranging from 28°C – 42°C while the time taken for subsequent cars to honk, and how many times, were recorded. The study found a linear increase in horn honking with increasing temperature, with stronger significance for subjects with their car windows down, assuming they did not have air-conditioning.

An interesting field experiment by Vrij et al. (1994) asked police officers to perform a training session on a simulated burglary under comfortable or hot conditions to test the impact of temperature on officers' tensions, perception and behaviour. Officers in hot conditions acted more aggressively, as well being more likely to draw their weapon and shoot. This is particularly concerning considering a subsequent study found that rifle marksmanship was also impaired by heat (Tikuisis et al., 2002). Other laboratory studies have found that hot temperatures increase hostile attitudes (Anderson et al., 1995), and that heat impairs performance of cognitive-related tasks such as visual and auditory vigilance, arithmetic and short-term memory (Kobrick & Johnson, 1991). Studies have also found heat to cause feelings of being upset, uncomfortable and distressed (Anderson et al., 1995).

2.5 A linear or non-linear relationship?

Although there has been consistency in finding relationships between temperature and aggressive crime rates in temporal studies, there is still much debate about if the relationship is linear, that is, as temperature changes, crime does proportionally, or non-linear, that is, thresholds are reached in which crime changes at a different rate. The nature of the relationship and shape has been discussed in depth in a series of journal articles (Anderson, 1989; Bell, 1992, 2005; Bushman et al., 2005; Cohn & Rotton, 2005).

Studies that have found a linear relationship include an Australian investigation by Auliciems and DiBartolo (1995) which looked at the weather and telephone calls to police reporting domestic violence in the city of Brisbane in Queensland in 1992. The study looked at daily incidences averaged weekly, and found a significant positive linear relationship between temperature and police calls (Figure 2.6).

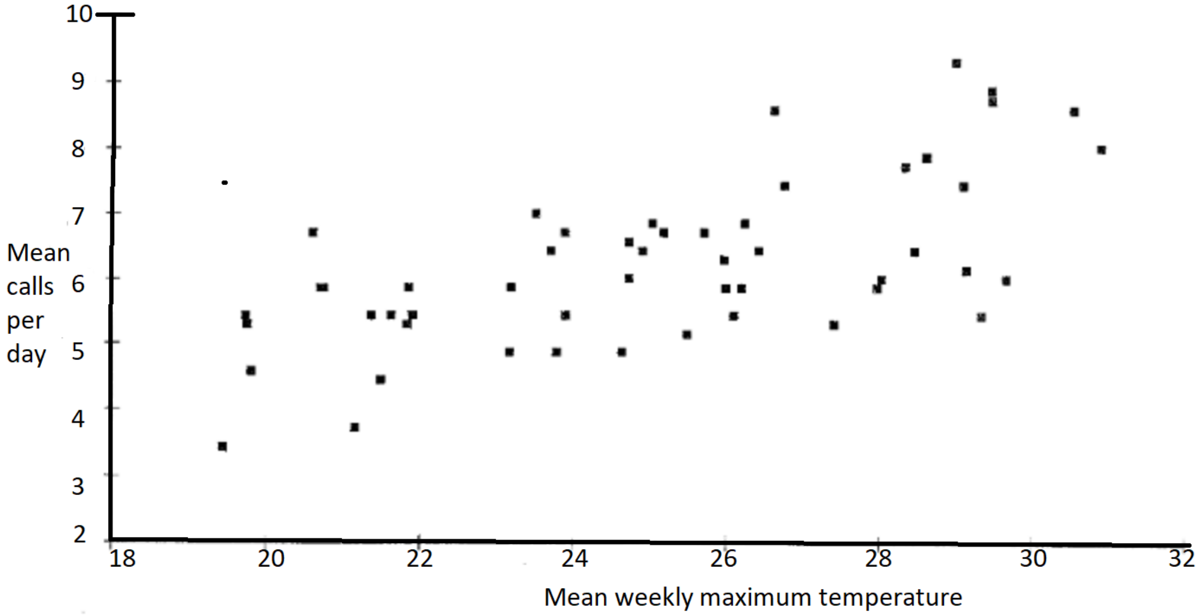

Figure 2.6: Mean daily number of police calls (averaged over a week) for domestic violence versus mean weekly maximum temperature, Brisbane, Australia, 1992. Reprinted from Auliciems & DiBartolo (1995), page 37

Ranson (2014) found a linear relationship between temperature and violent crime for the entire range of temperatures experienced in the continental United States. Rotton and Frey (1985) examined domestic violence in relation to temperature fluctuations and found a positive linear correlation.

Other studies have found a response 'curve', with an incline or decline in violence at extremely high temperatures. Rotton and Cohn (2001) studied domestic violence complaints in Minneapolis for 1987 and 1988 and found that temperature correlated with the number of complaints. However, the number of complaints increased with temperatures up to 26°C and then declined with temperature beyond this (Figure 2.7).

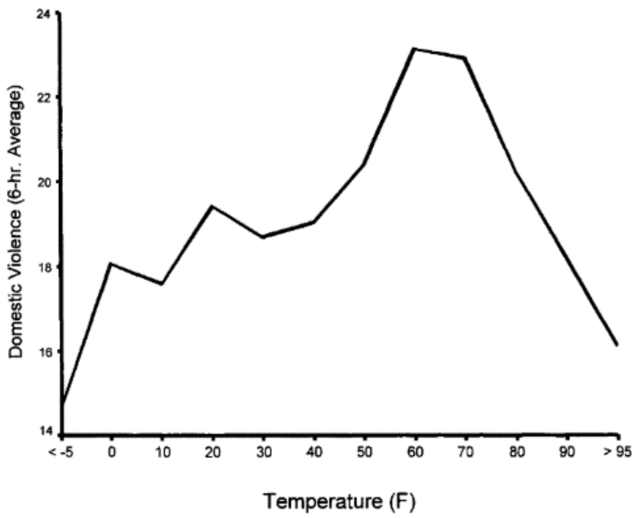

Figure 2.7: Six-hour average domestic violence as a function of temperature, Minneapolis, 1987 and 1988. Reprinted from Rotton and Cohn (2001), page 209

Horrocks and Menclova (2011) found a similar temperature point for a downturn of violent crimes. When the temperature was lower than 27°C, maximum temperature had a positive and significant correlation, but when greater than 27°C the maximum temperature had a negative but insignificant correlation with violent crimes. Gamble and Hess (2012) looked at daily ambient temperatures in Dallas, Texas, and found a positive relationship up to 27°C, which then turned to a negative relationship beyond 32°C. As Anderson et al. (2000) note, 'at extremely high temperatures, everyone gets sick and dies, precluding aggressive acts', which implies that the relationship must eventually become non-linear at some temperature point.

There may be a difference in the shape of the relationship for aggressive or non-aggressive crimes. For example, although Ranson (2014) found a linear relationship for aggressive crime, they found a highly non-linear relationship for property crime for temperatures above 10°C.

2.6 Climate change and crime

There is an emerging field of research on how anthropogenic, rapid climate change may influence inter-personal violence. Ranson (2014) used US crime rates and climate projections to determine future increases. The study projected that in the year 2090, crime rates for most offence categories will be between 1.5 - 5.5% higher due to climate change. The United States would experience, among other categories, an additional 22,000 murders, 180,000 cases of rape, 1.2 million aggravated assaults and 2.3 million assaults compared to the total number of occurrences that would have occurred between 2010 and 2099 in the absence of climate change. Hsiang et al. (2017) reviewed past studies and found that violent crime rates increase at around 0.88% per 1°C, and, projected that the United States would experience a linear increase of violent crime as temperatures increase.

2.7 Theories explaining the crime-temperature relationship

The results from temporal, spatial and experimental studies indicate that heat and aggression and/or crime are related. However, the question remains whether temperature plays a direct causal role, or if there are alternative explanations. A range of theories has been proposed to explain the relationship, which can work independently or in concert.

The General Affective Aggression (GA) model suggests an interaction between biological and psychological processes that can explain why individuals choose, under certain conditions, to respond in an aggressive manner to external stimuli (Mares, 2013; Anderson et al., 1995). Anderson et al. (2000) proposed a diagram explaining the GA model and the four main foci of the model: input variables; present internal state; appraisal processes; and outcome (Figure 2.8). Under GA assumptions, violence increases with temperature and is not predicted to decline until extremely high temperatures are reached.

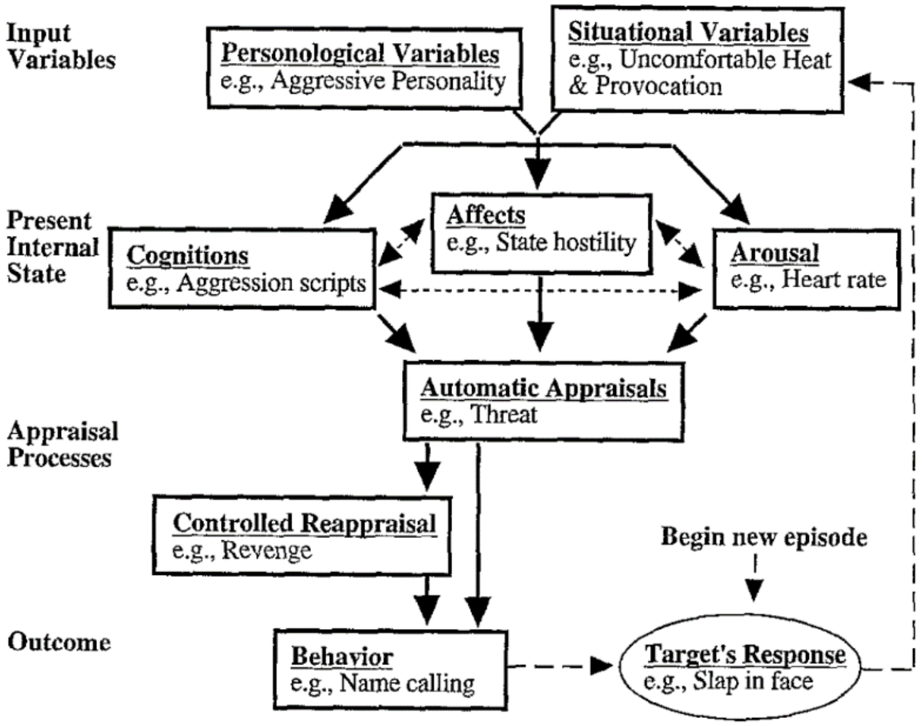

Figure 2.8: General Affect Aggression Model. Reprinted from Anderson et al. (2000), page 79

The Negative Affect Escape (NAE) model (Baron & Bell, 1976), suggests that aggression increases with temperature because of physical irritation and discomfort caused by the heat. However, this relationship is only up to a certain temperature. After this point, the relationship changes to a negative correlation as the discomfort increases to a level where the motivation to escape the uncomfortable situation outweighs the motivation to be aggressive (Bell, 1992). Therefore, there may be an 'inverse-U-shaped' relationship between temperature and aggression. As aggression increases then decreases, the expected crime from aggression also increases then decreases. The NAE model has been used to explain inconsistencies in the shape of the aggression-heat relationship in experimental studies compared to real world studies; in a controlled situation, the participant does not have an 'escape' opportunity (Anderson, 1989). It may also explain why in real world studies, uncomfortably cold weather doesn't appear to increase violence, however does so in a laboratory environment where participants are unable to seek means to avoid the discomfort. In the real world, relief from cold discomfort may be more available (e.g., from clothing, fire, heating systems) than relief from heat discomfort (Anderson & Anderson, 1998).

A third key theory is Routine Activity (RA), developed by Cohen and Felson (1979), that explains the relationship between heat and crime through warmer weather creating behavioural change, and hence more opportunities to commit crime. For example, an increase in violent crime during the summer could relate to young people out of school or family holidays. Warmer weather may also lead to people leaving their windows open, providing more opportunity for property crime. People may drink more alcohol during increased social interactions or because of the warm weather. Increased alcohol consumption has frequently been linked to increased violence and domestic assault (Klostermann & Fals-Stewart, 2006). Like NAE theory, RA theory could also explain why aggression may drop at higher temperatures; as the heat becomes more uncomfortable people retreat indoors and reduce their social interactions.

A new and emerging theory, proposed by Van Lange et al. (2017) is Climate, Aggression and Self-control in Humans (CLASH). CLASH proposes that rather than weather affecting aggression, it is a cultural-evolutionary explanation. People who live in hotter or colder climates adapt and develop cultural customs to suit the climate. Climate shapes culture, and the way a person reacts is largely a produce of the culture they were raised. This is supported by some studies that have found aggression and violence increase as distance to the equator decreases (United Nations Office on Drugs and Crime, 2013; Walker et al., 1992).

The theories need not be seen in isolation, but rather several processes or motivations may be working at the same time. For example, change in routine activities (RA theory) may see more people out socialising, where the General Affect model causes people to feel more aggressive, hence in combination there is an increase in crime. Likewise, no single theory can explain the relationship between heat and crime – for example, RA theory may see an increase in crime in summer months, however it cannot explain the outcomes of experimental studies where routine is not a factor.

2.8 Chapter summary

This chapter has provided a summary of the research to date on the crime-temperature relationship, specifically on heat and aggression. There have been mixed findings from experimental methodologies, as well as those that have investigated non-aggressive crimes such as theft. Results that are more consistent are temporal studies relating to aggressive crimes and heat. As to why this relationship occurs, there is a range of theories that suggest behavioural change, culture or physiology. The following chapter is a journal article that investigates if heat and crime are correlated within a state of Australia, and if so, which of the theories could explain these relationships.

3. Journal manuscript

The following manuscript has been submitted to the New South Wales Department of Justice, Bureau of Crime Statistics and Research for pre journal submission review. This is a requirement of BOCSAR's provision of crime data to researchers, to ensure the anonymity of crime offenders and victims is maintained when such manuscripts are published. The manuscript is intended for submission to the *Journal of Environment and Behavior* (SAGE journals).

Statement of authorship:

Heather R. Stevens is the principal author, as indicated through the first author position. Stevens has taken a primary role in the conception, data collection, analysis and writing of the paper. The three co-authors (Beggs, Graham, and Chang) have together played a secondary, supervisory/guiding role, with their individual contributions decreasing with progression through the authorship list. Graham provided guidance on the temporal analysis component of the research, while Chang provided guidance on the spatial analysis component.

The relationship between temperature and crime in New South Wales, Australia

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Abstract

This study used both temporal and spatial models to investigate the relationship between temperature and key crimes in New South Wales, Australia. Results suggested that assault and theft counts were significantly higher in summer than winter (18 and 6%, respectively), while fraud counts were not significantly different. Using maximum monthly temperature, results indicated that for every 10°C increase in temperature, average monthly assaults significantly increased by 22%, and thefts by 3.5%, while again, there was no evidence of a relationship between temperature and fraud. Modelling daily average counts revealed similar results. The study also found that for every 10ºC increase in temperature, a violent crime was 14 to 16 times more likely than a nonviolent. 96% of Local Government Areas (LGAs) in NSW had a higher summer assault rate than winter, and LGAs experience significantly differing responses. The findings of this study provide an empirical foundation for understanding crime-temperature relationships.

Keywords: aggression, heat, assault, theft, time series regression

Introduction

There is a common assumption that hotter weather makes us irritable. The relationship between temperature and deviant behaviour is entrenched in the English language, with phrases such as ‘hot-headed’, ‘hot under the collar’ and a ‘simmering anger’ commonly referring to feelings of anger or aggression. Studies have found a correlation between warmer temperatures and aggressive behaviour and/or crime at temporal scales ranging from hour to millennium and spatial scales from buildings to the globe (Anderson et al., 2000; Cohen & Krueger, 2016; Hsiang & Burke, 2014; Michel et al., 2016; Plante & Anderson, 2017; Ranson, 2014).

Crime currently costs the Australian economy around AUD47.6 billion per year (Smith et al., 2014) as well as having indirect social and economic costs to victims, their networks, witnesses and even the offenders. Incidents of theft and fraud are the most commonly reported crimes nationally and contribute 37% of the cost of crime. Crimes against the person, including assault and homicide, make up 15% of total cost (Smith et al., 2014). Assault is an offence that often goes unrecorded, and as such the actual number of assaults is estimated to be much higher (approximately 6.9 times) than officially recorded (Rollings, 2008; Smith et al., 2014).

New South Wales is renowned as a state of extremes, with heatwaves a common occurrence. This is likely to worsen, with projections of maximum temperatures increasing by 1.8°C to 2.6°C, and minimum temperatures by 1.4°C to 2.6°C by 2070 (NSW Office of Environment and Heritage, 2013). Numerous studies have indicated that a warmer climate could lead to increased interpersonal conflict (Hsiang et al., 2017; Hsiang & Burke, 2014; Ranson, 2014).

This study aims to assess relationships between temperature or its surrogate, season, and crime in the state of New South Wales, as well as the Greater Sydney Region using data from the NSW Bureau of Crime Statistics and Research, the Australian Bureau of Meteorology and the Australian Bureau of Statistics. Specifically, it aims to:

- Model the seasonal relationship for the offences assault, theft and fraud;
- Model the relationship between maximum monthly temperature and monthly offence counts;
- Model the relationship between maximum daily temperature and daily count of offences, controlling for holidays and weekends;
- Investigate whether temperature influences the odds of a violent versus a nonviolent offence, and;
- Model and map spatial differences in assault and temperature relationships.

The results of the study are discussed in the context of the theories as to why temperature and crime may be related, and how these theories could apply in the Australian climate. Understanding the relationships between heat and crime in Australia may enable better allocation of police and health resources, as well as development of policies and programs to reduce crime. Establishment of such relationships may also be useful for understanding how crime may change in a warming climate.

Literature review

Most previous studies (Anderson et al., 2000; Field, 1992; Horrocks & Menclova, 2011; Jacob et al., 2007; Mares, 2013; Ranson, 2014) suggest a positive correlation between higher temperature and more violent crimes, as well as higher burglary, theft and robbery counts. The relationship between fraud and temperature, however, has not been well researched.

Methodologies for studies to date tend to fall into three, not mutually exclusive, categories: temporal, spatial, and experimental. Temporal studies examine the relationship between temperature and crime of a region(s) over time. They have been conducted at a range of spatial scales (i.e., countries, states and cities) as well as time scales (i.e., years, seasons, months, days and hours). In most cases, research has found occurrences of violent crime peak in the summer months and with higher temperatures (Breetzke & Cohn, 2012; Cohn, 1990; Harries & Stadler, 1988).

An Australian study by Auliciems and DiBartolo (1995) looked at police calls relating to domestic violence in Brisbane over a 12 month period, accounting for effects of the day of the week, and observed significant positive associations between calls and maximum air temperature, during all seasons. Using monthly crime data, a large-scale study by Ranson (2014) found that for 2997 counties in the USA, higher temperatures resulted in more crime across a range of offences including murder, rape and vehicle theft.

Temporal studies can also look at 'irregular' temperature variations by analysing crime against weekly, daily, or even hourly temperatures. For example, Jacob et al. (2007) modelled weekly data across 116 jurisdictions in the USA over a 6 year period, finding an approximate 6°C increase in weekly temperature was associated with a 5% increase in violent crime. Cohn and Rotton (2000) and Rotton and Cohn (2001) studied disorderly behaviour in Minneapolis at a daily scale and found that temperature was significantly correlated, with incidents increasing with rising temperatures up to 26°C, and then declining.

Spatial studies compare how crime or crime proxies and temperature relationships vary between geographic regions (i.e., countries, states, cities, or sub-city areas) that are similar in many respects, but differ in climate. For example, Lester (1986) compared homicide rates of the 45 largest metropolitan areas in the USA, finding that state homicide rates varied gradually, rather than abruptly, with latitude. At a city scale, Brunsdon et al. (2009) looked at crime rates of an urban area in the UK using geographical coordinates of police calls, finding that both temperature and humidity exert significant effects on the spatial patterning of incidents of disorder and disturbances. Some studies combine both spatial and temporal methodologies. For example, Butke and Sheridan (2010) modelled 10 years of aggressive crime and temperature in Cleveland, Ohio, to find that aggressive crime generally increased as apparent temperature increased. The study went on to analyse the same city geographically, finding that the spatial patterns of crime were minimally influenced by hotter weather.

The third key method of investigation into the relationship between temperature and aggression is within a controlled (experimental) environment. These studies have drawn on a wide range of methodologies from psychology to sports physiology, and used proxies for aggression such as car horn use (Kenrick & MacFarlane, 1986), police officers drawing fire (Vrij, 1994) and participants administering electric shocks (Baron & Bell, 1976). Results of controlled studies have been varied (Anderson et al., 2000).

Theoretical context

Temporal, spatial and experimental studies have provided strong evidence that temperature and crime and/or aggression are associated with one another. The ongoing challenge is to determine whether temperature plays a direct causal role, or if there are related or alternative explanations. There have been a range of theories proposed to explain the association, which can work independently or in cooperation.

The Negative Affect Escape (NAE) model (Baron, 1972; Baron & Bell, 1976) suggests that aggression increases with temperature because of physical irritation and discomfort caused by heat. However, this relationship is only up to a certain temperature. After this point, the relationship changes to a negative correlation as the discomfort increases to a level where the motivation to escape the uncomfortable situation outweighs the motivation to be aggressive (Bell, 1992). The General Affective Aggression (GA) model suggests an interaction between multiple biological and psychological processes that can explain why individuals choose, under certain conditions, to respond in an aggressive manner to external stimuli (Mares, 2013). Under GA assumptions, violence is predicted to increase linearly, until extremely high temperatures are reached (Anderson et al., 2000).

The Routine Activity (RA) theory, developed by Cohen and Felson (1979), proposes that warmer weather creates behavioural change and greater opportunities to commit crime. For example, an increase in violent crime during summer could relate to young people out of school or on holidays. People may drink more alcohol during increased social interactions or because of the hot weather - increased alcohol consumption has frequently been linked to increased violence and domestic assault (Klostermann & Fals-Stewart, 2006). Warmer weather may also lead to people leaving their windows open or leave their houses vacant while on holiday, providing more opportunity for theft. Cohn et al. (2004) expanded the RA and NAE theories to develop the Social Escape/Avoidance theory, which suggests people will attempt to avoid conditions that could lead to negative outcomes. This could explain why crime can drop at higher temperatures - as the heat becomes more uncomfortable people retreat indoors and reduce their social interactions. A new and emerging theory, proposed by Van Lange et al. (2017) is Climate, Aggression and Self-control in Humans (CLASH). CLASH proposes that rather than weather affecting aggression, it is a cultural-evolutionary explanation. People who live in hotter or colder climates adapt and develop cultural customs to suit the climate. Climate shapes culture, and the way a person reacts is largely a produce of the culture they were raised.

The theories may not work in isolation, but rather several may occur concurrently. For example, change in routine activities (RA theory) may see more people out socialising, simultaneously, high temperatures causing people to feel more aggressive (GA model). Likewise, no single theory can explain the relationship between heat and crime. For example, RA theory may see an increase in crime in summer months, but it cannot explain the outcomes of experimental studies where routine is not a factor.

Methodology

Location

This study investigates crime within the eastern Australian state of New South Wales (NSW), and the Greater Sydney Region (GSR) (darker blue shaded area of Figure 1). NSW has 152 Local Government Areas (LGAs) and is home to 7.7 million people, with 63% living within the GSR (NSW Department of Premier and Cabinet, 2018). For this study, the GSR is considered to be the 41 LGAs as governed by the NSW Department of Planning's Greater Sydney Commission (Greater Sydney Commission, 2018).

NSW is within the temperate climatic zone, with average maximum temperatures for the coast ranging from 26°C in summer to 16°C in winter (NSW Environment Protection Authority, 2015). Inland areas have varied temperatures depending on elevation, latitude and proximity to the coast, with regions of hot and dry deserts in the north-west, and areas of winter snow in the south-east.

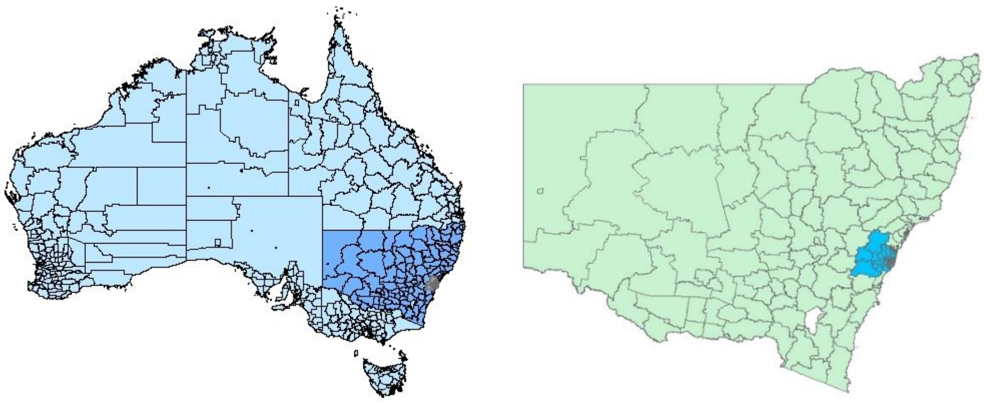

Figure 1: Study locations: State of New South Wales, Australia (shaded, left) and the Greater Sydney region (shaded, right), lines showing Local Government Areas

Data

Crime data

Crime data was obtained from the NSW Department of Justice, Bureau of Crime Statistics and Research (BOCSAR), for the 11-year period from January 2006 to December 2016. Two datasets were used. One was a publicly available dataset (NSW Bureau of Crime Statistics and Research, 2017), which included aggregated monthly incidents of offence categories for each LGA. The second was obtained via request from the Bureau, and included a single record for each individual incident, its date and location (BOCSAR reference NM1715202).

Three offence categories were selected for this study: assault (including subcategories of domestic violence-related assault, non-domestic violence-related assault, and assault against police), theft (including subcategories of break and enter dwelling, break and enter non-dwelling, receiving or handling stolen goods, motor vehicle theft, steal from motor vehicle, steal from retail store, steal from dwelling, steal from person, stock theft, and other theft), and fraud. These crime categories were selected as they are a representation of the most common offences in NSW.

Meteorological data

For NSW, gridded climate data comprising the mean and maximum monthly temperatures based on a standard climatological period of 30 years (1961-1990) was obtained from the Australian Bureau of Meteorology (BOM). It was downscaled using zonal statistics technique (Environmental Systems Research Institute, 2016) to compute values for each LGA. For the GSR, daily and monthly mean temperature data was obtained from the BOM Parramatta weather station (Station number 66124, World Meteorological Organization number 94764). This weather station was selected to represent the temperature of the region because of its central proximity as well as length and consistency of data.

Socio-economic data

Population and socio-economic data was obtained from the Australian Bureau of Statistics (ABS). The most recently available (2011) Socio-Economic Indexes for Areas (SEIFA) were used: Index of Relative Socio-Economic Disadvantage, Index of Relative Socio-Economic Advantage and Disadvantage, Index of Education and Occupation, and Index of Economic Resources. The Index of Relative Socio-economic Disadvantage summarises a range of information about the economic and social conditions of people and households within an area and includes only measures of relative disadvantage. The Index of Relative Socio-economic Advantage and Disadvantage is similar, but it includes both relative advantage and disadvantage measures. The Index of Economic Resources focuses on the financial aspects of relative socio-economic advantage and disadvantage, by summarising variables related to income and wealth. Finally, the Index of Education and Occupation is designed to reflect the educational and occupational level of communities (Australian Bureau of Statistics, 2013).

Data analysis

Temporal analysis

The aggregated monthly dataset was initially visualised through time series decomposition plots to examine seasonal patterns and change over time using an additive model. Seeing a seasonal trend, a linear regression model using monthly counts as the response with season and year (centred on 2006) as predictors was applied to each offence category for NSW to determine whether summer and winter counts differed significantly. The individual unit counts were then aggregated daily, monthly and by season, and restricted to the Greater Sydney Region. A time series regression model was run on monthly counts of assault, theft and fraud to determine its relationship with monthly maximum monthly temperatures, and displayed graphically. A time series regression model for daily counts was then developed using daily maximum temperatures as a predictor, controlling for weekends and 7 annual public holidays. Daily count data was plotted together with fitted linear and a loess smoothing lines (Cleveland, 1979). Assault daily count data had outliers that correlated to New Year's Eve or New Year's Day, which was removed in the assault and temperature plot.

To investigate the odds of a violent versus nonviolent crime being influenced by temperature, a logistic regression model was run controlling for yearly trend. Assault was selected to represent violent crime, and fraud as a representation of a nonviolent crime.

The significance level was set at 0.05. Analyses were undertaken using the statistical computing package R, version 3.3.2 (R Core Team, 2016) via the R studio interface (R Studio Team, 2015). The Forecast package (Hyndman & Khandakar, 2008) was used for time series analyses.

Spatial analysis

Base maps were created using the Australian Bureau of Statistics shape files for NSW LGAs (ABS, 2016) . Monthly and seasonal average incidents of assault were converted to rates by using the 2011 LGA population data. Summer rates of assault, as well as the difference between summer and winter rates were mapped. To investigate any spatial correlation, an Exploratory Regression model was run using mean maximum temperatures and the four SEIFA socio-economic deciles. This model finds the most suitable variables for a global Ordinary Least Squares (OLS) model. A OLS model was then run which also models quantile regression (Koenker Statistic), which indicates if the variables in the model are non-stationary (Koenker, 2005). If non-stationarity was found, a Geographically Weighted Regression (GWR) would be modelled and mapped, using monthly averages for temperature and assault rates. Spatial analysis was undertaken using ArcGIS 10.4 (Environmental Systems Research Institute, 2012).

Results

Temporal analysis

Seasonality of offences

Summary counts for the offences assault, theft and fraud for NSW aggregated by month and season are shown in Table 1. Theft was the most common offence, with an average of 18,210 incidents per month. Assault had on average 5,583 incidents per month, and fraud 3,501 offences per month. Among assaults, summer had the highest average monthly incidents, while for theft autumn had the highest average monthly incidents and for fraud it was winter.

Table 1: Monthly descriptive statistics for assault, theft and fraud. New South Wales, 2006 - 2016

Offence category	Mean	Standard Deviation	Median	1st quartile	3rd quartile
Assault counts per:					
Month	5583	545	5508	5170	5931
Summer month	6059	433	6011	5807	6439
Autumn month	5567	538	5447	5130	5896
Winter month	5083	330	5096	4809	5254
Spring month	5622	366	5624	5463	5797
Theft counts per:					
Month	18210	2330	17790	16490	19880
Summer month	18420	2246	18360	16580	19760
Autumn month	18740	2413	18420	16770	20600
Winter month	17650	2386	17040	15890	19680
Spring month	18040	2230	17760	16490	19870
Fraud counts per:					
Month	3501	627	3410	2939	4061
Summer month	3430	665	3166	2940	3954
Autumn month	3462	672	3462	2998	4289
Winter month	3519	672	3429	3062	3954
Spring month	3426	672	3384	2821	3962

Figure 2 shows time series decomposition plots of the aggregated monthly incidents for assault, theft, and fraud. The plots show (from top to bottom) the original time series, the estimated trend component (change over time), the estimated seasonal components and the estimated random component. The estimated trend components indicate that both assault and theft decreased over time, while fraud increased. The estimated seasonal component for assault showed clear peaks in the warmer months and a trough in colder months while theft and fraud showed no clear seasonal pattern.

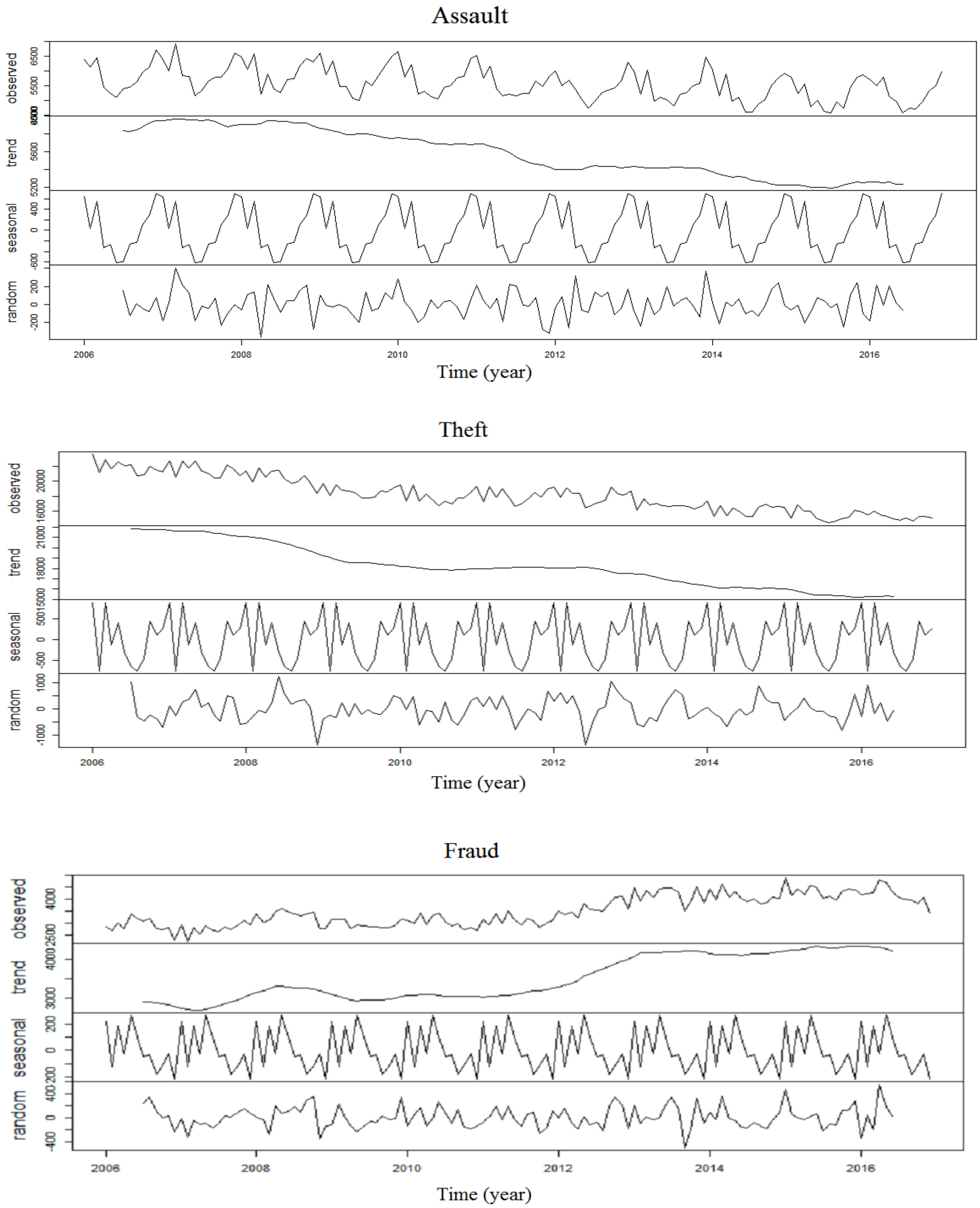

Figure 2: Decomposition plots of aggregated monthly incidents of assault (top), theft (middle), and fraud (bottom), New South Wales, 2006 - 2016

Table 2 shows the results of a linear regression for the three offence categories, adjusting for year (which was centred on 2006 so that the intercept is the average count in winter 2006). Spring, summer and autumn had significantly higher assault counts compared to winter (p <0.001), with summer seeing 976 (18%) more incidents of assault on average than during winter. Theft counts were significantly higher in summer and autumn compared to winter (p <0.001), with an additional 774 incidents (4% more) on average during summer than winter. Fraud counts in spring, summer and autumn were not significantly different to winter counts.

Table 2: Linear model for assault, theft and fraud, New South Wales, 2006 – 2016 with 95% confidence intervals (CI)

	Assault		**Theft**		**Fraud**	
	Estimated count (95% CI)	p value	Estimated count (95% CI)	p value	Estimated count (95% CI)	p value
Intercept	5488 (5340,5636)	<0.001	21004 (20625, 21382)	<0.001	2700 (2548, 2851)	<0.001
Season (ref = winter)		<0.001		<0.001		0.065
Spring	540 (376, 704)	<0.001	389 (-31, 809)	0.069	-92 (-260, 76)	0.278
Summer	976 (812, 1141)	<0.001	774 (354,1193)	<0.001	-88 (-256, 80)	0.299
Autumn	484 (320, 648)	<0.001	1088 (669, 1508)	<0.001	108 (-60, 627)	0.206
Year	-81 (-99, -63)	<0.001	-507 (-718, -624)	<0.001	163 (145, 183)	<0.001
Adjusted R Squared	0.620		0.860		0.700	

Monthly relationship between offence and temperature

Investigating the three offence categories at a monthly scale, crime data for 2006 to 2016 were limited to the Greater Sydney Region and plotted against mean monthly maximum temperature (Figure 3). The scatter plot for assault shows a clear positive linear relationship in which higher counts are observed at higher temperatures. For theft, there is a weak positive trend with more variability in the data, and no apparent relationship exists for fraud.

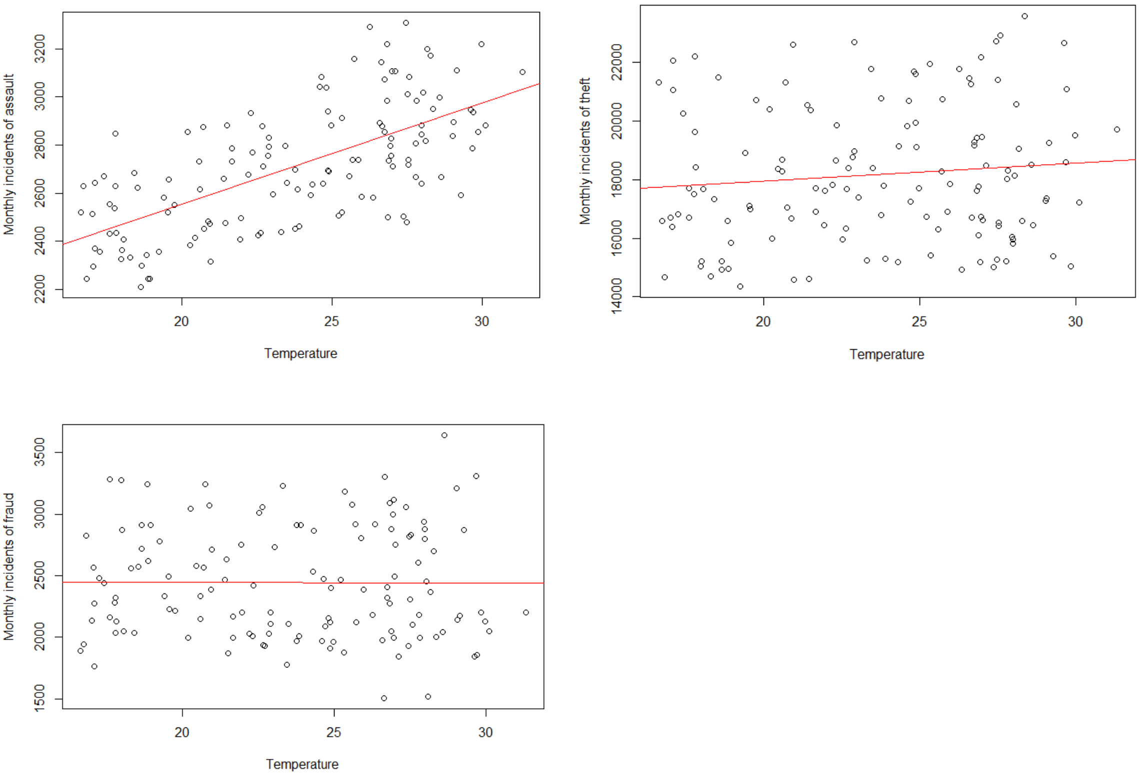

Figure 3: Scatter plots showing monthly count of incident against mean maximum temperature (°C) with linear regression lines. Assault (top left), theft (top right) and fraud (bottom). Greater Sydney Region, 2006 – 2016

An additive time series model was run for monthly count against temperature, adjusted for annual trend. The model indicated that for every 1°C increase in temperature, there are 43 more incidents of assault on average per month, a 2.2% increase per degree. For theft, there were 71 more incidents on average per month for every 1°C increase in temperature, a 0.35% increase per degree. The relationship between temperature and fraud was not significant (Table 3).

Table 3: Relationship between average monthly incidence of assault, theft, and fraud and maximum monthly temperature in Greater Sydney Region, 2006 - 2016

	Assault		**Theft**		**Fraud**	
	Estimated count (95% CI)	*p* value	Estimated count (95% CI)	*p* value	Estimated count (95% CI)	*p* value
Intercept	1920 (1765, 2076)	<0.001	20225 (19302, 21148)	<0.001	1891 (1576, 2206)	<0.001
Year	-3 (-4, -3)	<0.001	-56 (-60, -52)	<0.001	9 (8,10)	<0.001
Temperature	43 (36,49)	<0.001	71 (34,108)	<0.001	-2 (-15,11)	0.752
ANOVA (Temperature)		<0.001		<0.001		0.753
Adjusted R Squared		0.680		0.860		0.600

Relationship between daily offence count and temperature

The three offence categories were aggregated to a daily count for the GSR and plotted against daily maximum temperature with a linear regression line (red) and a locally weighted scatterplot smoothing (loess) line (blue) (Figure 4). The loess line for assault shows a slight nonlinear trend (plateauing) past 30°C, however with less data above that temperature, observed patterns are debatable. Both theft and fraud are largely flat, indicating no apparent relationship between daily counts and temperature.

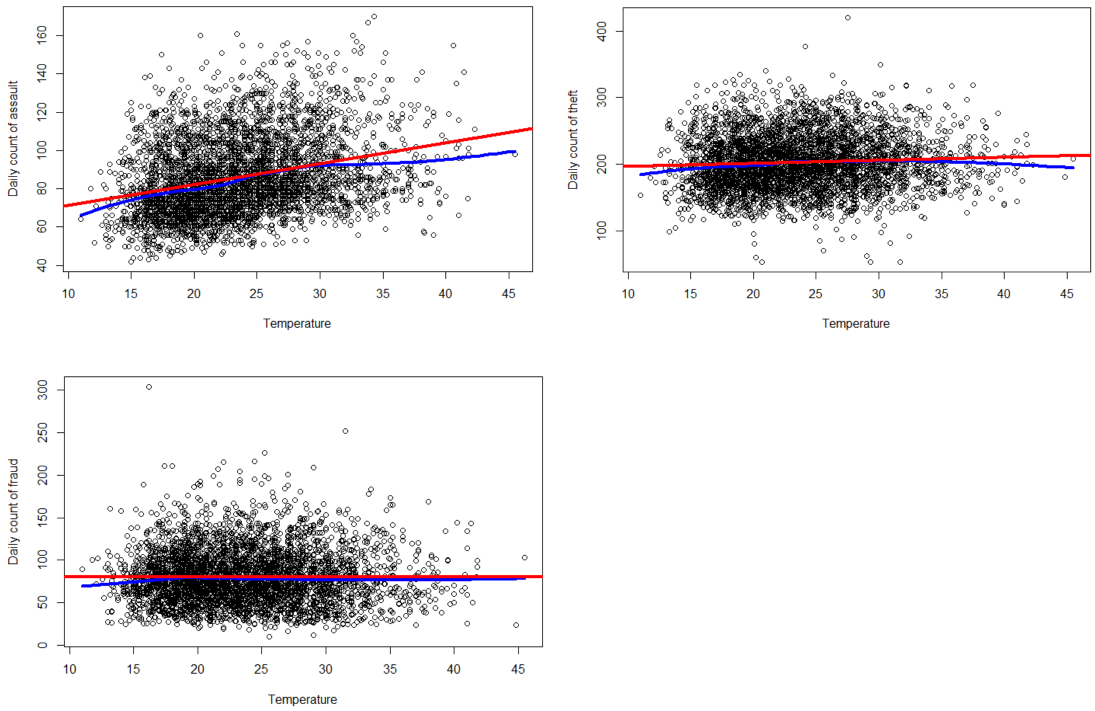

Figure 4: Scatter plots of daily count of incident against daily maximum temperature (°C) with linear regression line (red) and Loess smoothing line (blue). Assault (top left), theft (top right) and fraud (bottom). Greater Sydney Region, 2006 – 2016

The results of the additive time series model for daily count, adjusted for trend and an indicator for if the day was a weekend or holiday are shown in Table 4. The Adjusted R Squared was lower than using monthly count, however, the results were similar. The model indicated that for every 1°C increase in temperature, there is approximately 1 additional incident of assault on average per day, a 1.86% increase. For theft, there was an additional 0.6 of an incident on average per day, a 0.26% increase. The relationship between temperature and fraud was not significant.

Table 4: Relationship between average daily incidence of assault, theft, fraud and maximum daily temperature in Greater Sydney Region, 2006 - 2016

	Assault		**Theft**		**Fraud**	
	Estimated count (95% CI)	*p* value	Estimated count (95% CI)	*p* value	Estimated count (95% CI)	*p* value
Intercept	59 (57, 61)	<0.001	242 (238, 246)	<0.001	70 (66, 73)	<0.001
Day	-0.004 (-0.004, 0.003)	<0.001	-0.021 (-0.021, 0.020)	<0.001	0.001 (0.009,0.201)	<0.001
Temperature	1.097 (1.018, 1.176)	<0.001	0.619 (0.463,0.764)	<0.001	0.061 (-0.079, 0.201)	0.392
Holiday or weekend	30 (29,31)	<0.001	-42 (-44, -41)	<0.001	-36 (-37, -34)	<0.001
ANOVA (Temperature)		<0.001		<0.001		0.732
Adjusted R Squared		0.559		0.578		0.394

The relationship between temperature and violent versus nonviolent crime

To investigate if temperature influenced the likelihood of a violent or nonviolent crime, a logistic regression model was run, adjusting for year (Table 5). The model shows a significant relationship between crime and temperature (p<0.001); for every 10°C increase, the relative odds of an assault versus a fraud were 1.14-1.16 times (14 to 16%) more likely.

Table 5: Odds of assault versus theft, Greater Sydney Region, 2006-2016

	Odds Ratio (95% CI)	***p* value**
Intercept	1.051 (1.027, 1.075)	<0.001
Temperature (10°C)	1.153 (1.144, 1.164)	<0.001
Year	0.940 (0.939, 0.942)	<0.001

Spatial analysis

Mapping seasonal difference in assault rates

A map of the NSW average summer rates of assault (per 100,000 population) (Figure 5, left, top) show higher rates in the north-west LGAs such as Central Darling (2528), Bourke (2056), Brewarrina (2017), Walgett (1395) and Moree Plains (985). The southern LGAs largely all experienced a lower summer assault rate. Within the Greater Sydney Region, the LGA of Sydney had the highest average summer assault rate (777), followed by western suburbs of Campbelltown (403), Blacktown (366), Penrith (317) and Parramatta (282) (Figure 5, left, bottom).

Mapping the difference between winter and summer rates (Figure 5, right, top) shows 96% of

NSW LGAs experienced on average higher rates of assault during summer than winter. Overall, LGAs with the greatest difference in rates (per 100,000 people) were the north-western LGAs of Central Darling (841), Brewarrina (504), Bourke (326) and Walgett (223), but also Byron Bay (134) and Moree plains (161). Regions that saw a decrease in summer included the Snowy River (-23), Bombala (-20), Blayney (-16), and Cobar (-13). For the GSR (Figure 5, right, bottom), all LGAs had higher summer assault rates than winter. The LGAs with the greatest difference in rates were Sydney (103), Waverly (73), Campbelltown (70) and Blacktown (54).

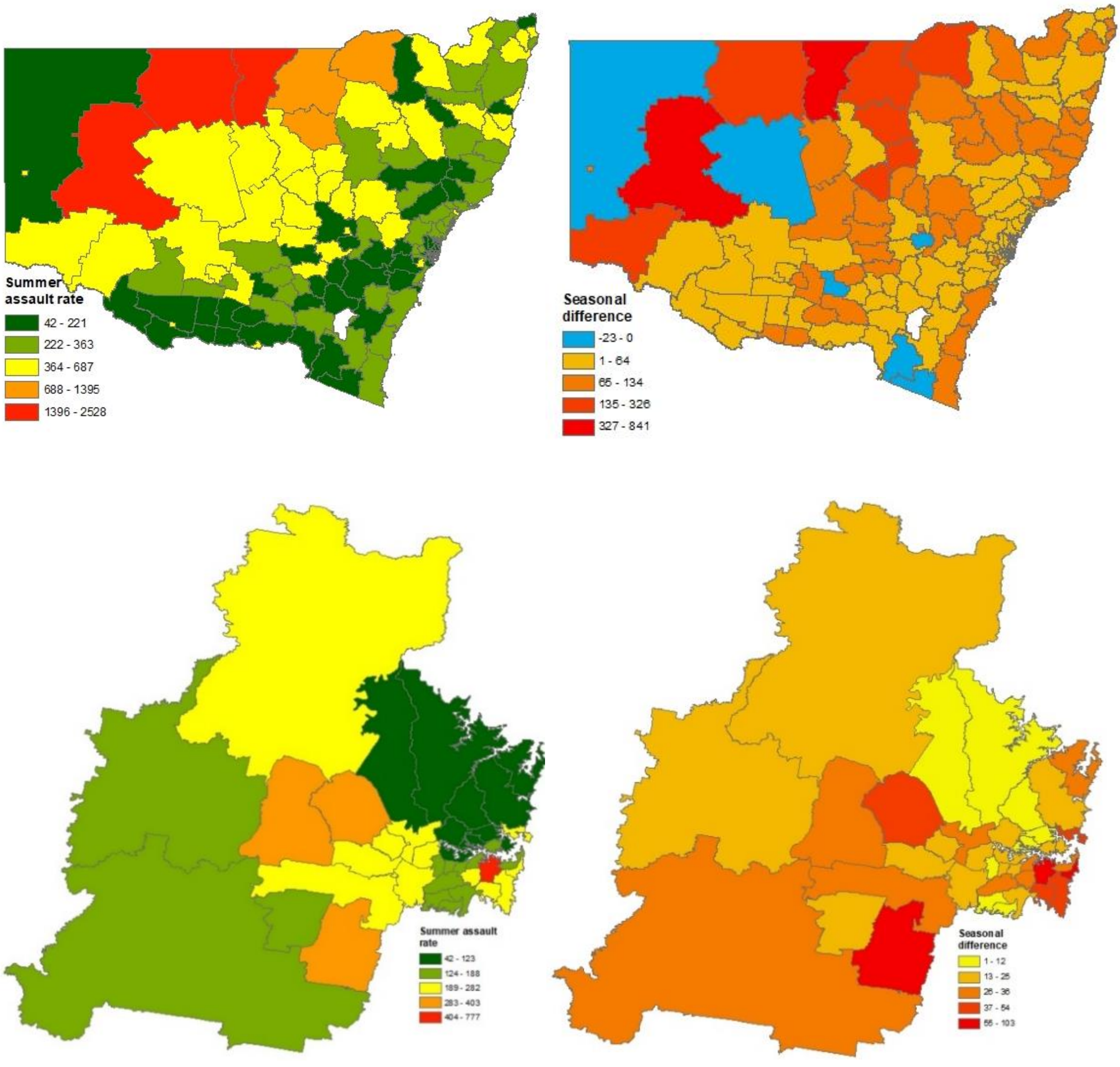

Figure 5: Average summer rates (per 100,000 population) of assault (left) and seasonal difference (summer – winter) (right), NSW (top) and the Greater Sydney Region (bottom), 2006 – 2016

Modelling the spatial relationship between temperature and crime

Exploratory Regression analysis found the most appropriate variables were the mean temperature and the Index of Economic Resources (Adjusted R-Squared 0.38, AICc 2131.35). Maximum temperatures and the other SEIFA indexes were discarded from further analysis.

A global OLS model showed that both temperature and the Index of Economic Resources were significant predictors of summer rates of assault across NSW. The OLS model indicated that for every 1°C in temperature, there was an additional 42 (7%) assaults per LGA. An increase in the Index of Economic Resources saw a reduction of 45 summer assaults per LGA (Table 6).

Table 6: Ordinary Least Squares regression estimates for assault, NSW

Variable	**Coefficient**	**Standard Error**	***p* value**
Intercept	583.06	232.57	0.0132
The Index of Economic Resources	-45.29	8.23	<0.001
Mean maximum temperature	41.85	7.66	<0.001
Adjusted R Squared			0.38
AICc			2131
Koenker (BP) Statistic			<0.001

The OLS Koenker (BP) Statistic was significant, indicating that the variables in the model were non-stationary, that is, the data differs spatially. Therefore, a GWR analysis was undertaken on monthly assault rates with monthly mean temperatures and the SEIFAR economic index. The GWR provided a linear regression for each LGA. The resulting Adjusted R Squared for the GWR model was 0.267.

The map of NSW (Figure 6, top) show that for every 1°C increase in temperature, monthly average assault rates increased in the western LGAs. Some central LGAs as well as north-east LGAs saw a small decrease. All GSR LGAs saw an increase in monthly assault rates with an increase in temperature, with higher increases in the inner and western LGAs (Figure 6, bottom).

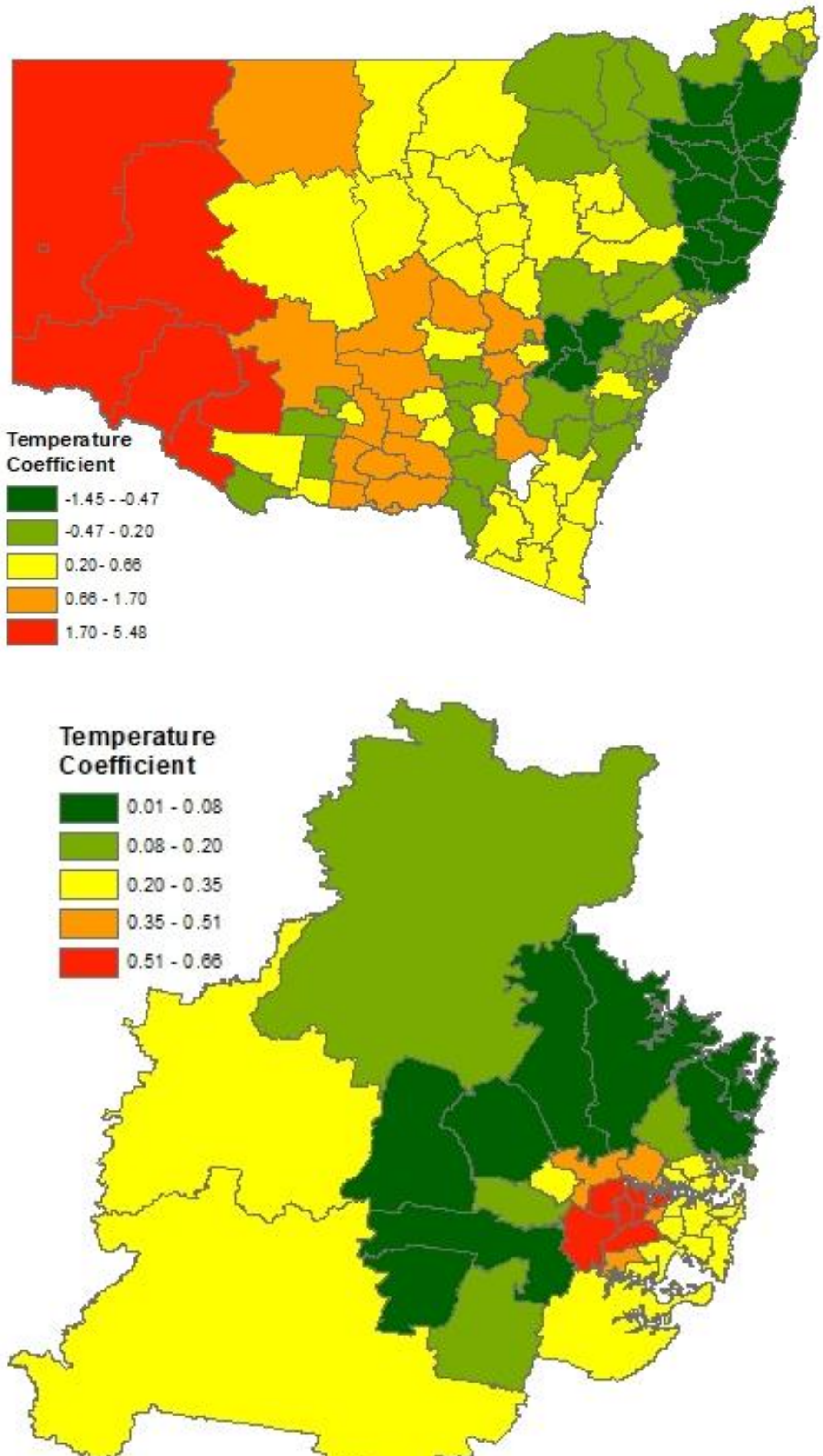

Figure 6: Geographically Weighted Regression temperature coefficient for monthly rates of assault in NSW (top) and Greater Sydney Region (bottom)

Discussion

Crime and temperature

Assault

Prior studies into the seasonality of assault have found a distinct peak in the summer months (Harries et al. 1984; Cohn 1990; Breetzke and Cohn 2012). This was also true of this study, with summer having on average 18% (976) more assaults than winter within NSW. Spatially, 96% of LGAs experienced higher assault rates in summer than in winter. The time series analysis found that for every 1°C increase in temperature, the Greater Sydney Region experienced 2.3% (43) more assaults on average per month, or 1.86% (1.1) more assaults per day. This finding is consistent with the 2.3% increase in interpersonal violence per standard deviation change in climate found in a meta-analysis by Hsiang et al. (2013).

Routine Activity Theory (Cohen & Felson, 1979) may explain the seasonal and monthly significance in assault, with warmer temperatures and the summer season seeing increased socialisation, holidays and travel, and alcohol consumption. In the Southern Hemisphere, the Christmas period is also during summer, which may be a period of increased financial strain. These changes in routine and financial strains could contribute to increased opportunity and motivation to commit an assault. However, there are also school holidays in June and July when assault rates drop, which could indicate other causes.

Assault was still significantly associated with temperature when controlling for weekend and holidays, which are a key time for routine changes. This finding could therefore support the General Aggression Affective model, that is, an increase in temperature creates an increase in irritability and therefore disposition to commit an assault. The GA theory could also influence the way police behave, resulting in increased aggression and more records of offence.

Within the literature, there has been ongoing debate regarding whether the relationship between temperature and assault is linear (that is, it increases directly proportionally to temperature) or if there are peaks or plateaus. This study plotted daily assault counts against daily maximum temperature, and used both a linear and Loess smoothing line. The Loess line indicated a slight plateauing above 30°C, however with limited data above that temperature, the shape is debatable. Studies such as Bell and Fusco (1989), Cohn and Rotton (2005) and Gamble and Hess (2012) have found that assaults decreased at temperatures of around 27-32°C. A slowing of assault counts at higher temperatures may be explained by the Negative Affect Escape model (Baron & Bell, 1976) in that, at higher temperatures, people seek means of avoiding situations that cause uncomfortable feelings. Police may also be less likely to patrol areas that are hot, reducing the number of arrests.

The spatial analysis indicated that LGAs in NSW experience different temperature and assault relationships. The findings are consistent with Kalkstein and Davis (1989), who found regional variability in the thresholds for heat-related mortality. LGAs that obtained the largest temperature coefficients were generally the same ones that experienced higher summer assault rates. Similarly, for the Greater Sydney Region, the western suburbs were both prone to higher summer assault rates as well as having a greater influence from temperature on assault. The findings somewhat support the CLASH theory (Rinderu et al., 2018) that proposes areas with hotter temperatures and less seasonal variation have higher crime rates due to cultural values of time-orientation and self control. It is worth noting however, that although temperature was significant to assault rates, in this study, the income index was a stronger signal. This is consistent with Coccia (2017), who analysed homicide rates across 191 countries to find that, although distance from the equator was significant, income inequality overpowered the role of hot weather to explain the level of homicides.

Both spatial models resulted in somewhat low Adjusted R-Squared of around 0.30, which means that the model was not capturing most of the variability in assault rates. Possible variables missed could be population density (per unit area), if it was an urban or non-urban area, the influence of the 'Heat Island Effect' (Oke, 1982), age, gender, cultural demographics or other socio-economic factors not captured by the SEIFA indices. Another variable not easily captured is population movement across LGAs during heat events, such as going to coastal regions or shopping precincts. As consistent with Cahill and Mulligan (2007), this study has found that the spatial results are best considered in parallel with a temporal study to accurately model the impact of temperature on crime.

Theft

Studies into the seasonality of property crime have had varying results, with some studies finding higher rates of property crime and or theft in summer (Cohn and Rotton 2000) or higher during winter (Landau & Fridman, 1993; McDowall et al., 2012). This study found theft to be significantly higher in summer than winter (4%), but higher still in autumn compared to winter (5%). The reason this study may have found an increase in theft during summer rather than winter is that, as mentioned previously, in the Southern Hemisphere, the Christmas holidays period occurs during summer. Christmas can be a period where people are more economically constrained, as well as more shoppers as potential targets (Landau & Fridman, 1993; McDowall et al., 2012). The increase in the autumn months of March and April could correlate to the Southern Hemisphere Easter holidays. Routine Activity theory would suggest that warmer temperatures may see more people leaving their windows and/or doors open for increased ventilation and creating more opportunity for theft, as well as people being drawn to air-conditioned shopping centres and hence potentially more stock theft. A study into global crime exposure found that that Australian lifestyle might actually be responsible for higher crime rates, because of our detached houses in big impersonal suburbs being a target for theft (Walker et al., 1992).

Another difference between this study and Northern Hemisphere studies is the climate. Northern Hemisphere studies have argued that theft may be more common in winter as it is a time when food, warmth and shelter are more critical. This would be true of regions that experience extreme winters. However, NSW is largely temperate, and the lowest monthly maximum temperature in this study was 7°C, which may not motivate incidents of theft as in colder climates.

Like assault, when controlled for holiday and weekend temperature was still significantly associated with theft, albeit a small increase of 0.26% (0.6) additional thefts per day for every 1°C increase in temperature in the Greater Sydney Region. The theft offence categories included theft against a person, which could be considered an act of aggression and, aligning with GA theory, explain why incidents of theft remained influenced by temperature.

Fraud

Fraud was not found to have significant seasonal or temperature relationships. Modelling also indicated that the odds of a violent crime (assault) were 14-16% more likely than fraud for every 10°C increase in temperature. Interestingly, as above, the seasonality of theft has been argued as motivated by economic gain, however fraud could also be considered to have similar motivations. A report prepared for the Bureau of Crime Statistics and Research noted that the most common types of fraud were card fraud, fuel drive-offs, identity theft, embezzlement and cheque fraud (Macdonald & Fitzgerald, 2014). As such, it could be expected that fraud would also be higher during the Christmas period. The challenge with investigating fraud is that it is not clear when the offence occurred – it may have been days, weeks, months or even years prior to the record of offence, and may have occurred over a long period of time. Therefore, the date of the recorded incident may not be a good indication of when it occurred.

Implications

This study places the forecasting of crime based on temperature and season on a firm empirical footing. Knowing that assault counts show seasonality and a significant positive relationship with temperature can allow for policing, hospitals and support systems to better allocate resources depending on projected peaks and troughs. This may mean ensuring that there are adequate resources for responding to offences, like putting on additional staff during summer or on hot days. However, the knowledge could also allow for pre-emptive measures such as patrolling certain areas at risk of theft or reaching out to communities who are more at risk from assault. Identifying that there are differences spatially in the assault and temperature relationships means that applying local responses, rather than a state-wide response, may be more effective.

Limitations and future work

This study had a number of limitations that could be addressed in future investigations;

Further modelling of daily and also hourly data could provide better understanding of ‘extreme’ temperature spikes, and may help explain some of the random variations that the seasonal decomposition plots identified. Daily analysis could also investigate the influence of ‘lagging’, that is, crime rates occurring after an extreme heat event, or how the duration of a heatwave influences crime.

This study looked only at mean monthly or daily maximum temperatures, however there are a number of other variables that have been found to correlate to crime, including humidity (Hu et al., 2017a; Hu et al., 2017b), wind speed, precipitation (Horrocks & Menclova, 2011; Pakiam & Lim, 1984) and sky cover (Cohn & Rotton, 1997). The dataset used included the premises type in which the incident occurred, which may help understand risk from ambient versus indoor (and possibly air-conditioned) environments. As well as additional crime records, some medical data could be insightful. For example, records of facial traumas were found to be significant to weather variables (Wilson & Thomas, 2017) while Dolney and Sheridan (2006) found ambulance calls increased on hot days.

Both spatial models found Adjusted R-Squared less than 0.30, indicating missing variables, and could benefit from applying more sophisticated models. This study looked at LGAs, however geocodes and thermal imaging ‘heat maps’ could be used to support finer scale analysis.

This study was purely empirical; however qualitative data such as interviews with police or hospital staff could help identify variables not considered, or better understand how the findings could be applied. The influence of age and gender of both the offender and the victim would provide greater insights into who is most vulnerable from the crime-temperature relationship.

Conclusion

The primary aims of this research were to determine if the common crimes of assault, theft and fraud were influenced by season and temperature within New South Wales, and if the relationship for assault differed between regions across the state. Firstly, the study found that both assault and theft are seasonal, and the number of monthly and daily incidents rise with an increase in temperature. Also that, as temperature increases, it is more likely that incidents of a violent, rather than a nonviolent crime will occur. Secondly, that almost all Local Government Areas in New South Wales have higher assault rates in summer than winter, and that there is spatial difference in the relationship between temperature and assault rates implying that a 'one size fits all' model across the state can't easily be applied.

This is the first temporal and spatial study within the Australian climate, as well as being one of only several Southern Hemisphere studies. We believe that the results presented in this study will be valuable for sectors such as law enforcement, health and social services.

End of journal article

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4. Synthesis and conclusion

This study provided an empirical assessment of the relationship between common offences and temperature in New South Wales and the Greater Sydney Region. It is the first study to combine both spatial and temporal data within Australia, as well as being one of only a few studies using crime and climate data from the Southern Hemisphere.

The study found that both assault and theft are seasonally significant, and as monthly or daily temperatures increase, so to do incidence of assault and theft. Fraud however, which was used as an example of a nonviolent crime, was not significantly related to temperature. Assaults are higher in summer than during winter for 96% of LGAs in NSW, although there are significant differences in this relationship, with some having a stronger correlation than others. The spatial modelling, however, had low goodness-of-fit, suggesting variables to better explain the relationship have been missed.

Figure 4.1 is an infographic presenting the key findings of this study, to be read in the context of within this thesis.

4.1 Applications of the study

The findings of this study could have a range of applications and be of interest to multiple stakeholders. These are described in the following sections.

4.1.1 Allocation of resources

Knowing there are peaks and troughs for assaults and thefts and that these crimes increase as temperatures increase could allow for better allocation of police, hospital and welfare service resources. This may mean ensuring that there are adequate resources for responding to offences, like putting on additional staff during summer or on hot days. However, the knowledge could also allow for pre-emptive measures such as patrolling certain areas at risk of theft or reaching out to communities who are more at risk from assault. At a national scale, a pre-emptive measure could be to widen the Australian Bureau of Meteorology’s heatwave alert services that forecasts upcoming heatwaves. Currently directed at local councils and emergency services, the alert services could also inform services that deal with assault.

4.1.2 Communication of risk

NSW has a state Heatwave Sub Plan, which aims to “detail the arrangements for the control and coordination of, the preparation for, response to and immediate recovery from heatwave events within NSW to reduce the risk or counter the effects on the community” (State Emergency Management Committee, 2011).

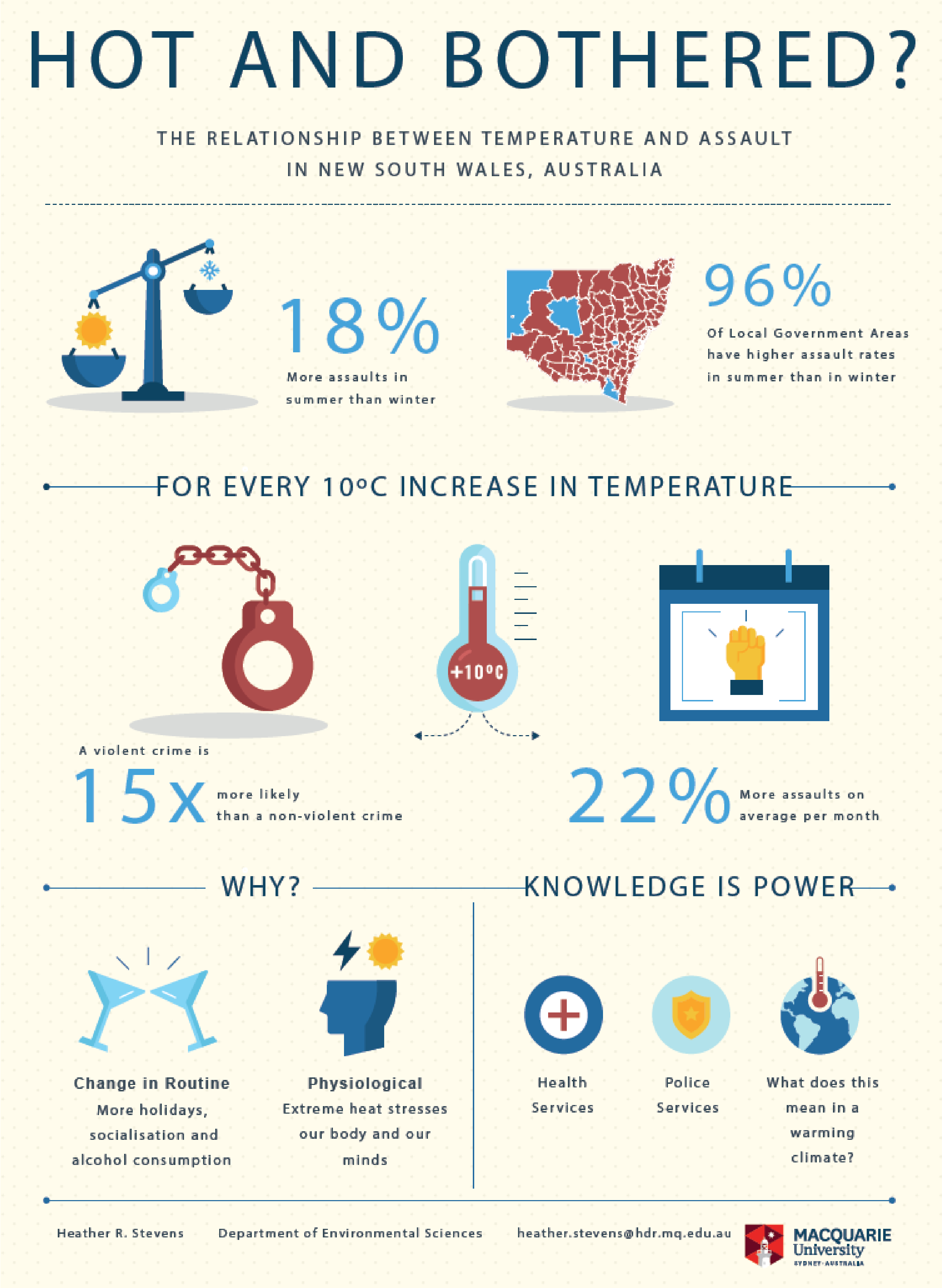

Figure 4.1: Infographic on findings from study

If policing and health services were aware of the seasonality and temperature relationships of crimes, particularly assault, they would be able to reallocate resources to meet the demand. How these services could plan for these changes would be a beneficial future study.

The findings of this study could also support better communication to those most at risk. Studies into heat mortality have found factors such as age, economics and social isolation may increase risk, while numerous studies have found that suicide corresponds to warmer temperatures (Dixon et al., 2014; Lester, 1986; Takahashi, 2017). Further investigation into those more at risk from the heat / crime relationship could allow for more targeted response.

4.1.3 Different plans for different regions

Knowing there is a significant difference in the relationship between temperature and assault across NSW and across the Greater Sydney Region indicates a need for a spatially tailored approach to action, and that a uniform state-wide approach may not be the most suitable response.

4.2 Future work

This study has been an initial assessment of the crime-temperature relationships in New South Wales. There are a number of elements that could be included in future studies, as detailed in the following sections.

4.2.1 Improvements on methodology

Additional modelling of daily or hourly data could allow for a better understanding into 'extreme' temperature spikes, and may help explain some of the random variations that the seasonal decomposition plots identified. Daily analysis could also consider the influence of 'lagging', that is, crime occurring after an extreme heat event or consecutive hot days.

The spatial analysis conducted firstly a global model on summer assault rates, but used monthly rates for the Geographically Weighted Regression to allow for a time series. Both models only found Adjusted R-Squared results around 0.30, indicating missing variables. Methods that are more sophisticated could be explored in future spatial analysis. This study looked at a scale of LGAs, however, it would be interesting to look at a finer resolution such as thermal imaging 'heat maps' aligned with police or ambulance callout locations or geocodes for recorded offences.

4.2.2 Additional variables

Additional weather variables such as humidity, wind speed, precipitation, cloud cover, or 'wet bulb' indices could be valuable. This study only used the three most common offences from 21 types, looking at each individually could help identify which crimes are most affected by temperature. Other crime, aggression or public health topics could be useful, such as hospital records for assault, suicide rates or data on access to domestic violence support services.

The data available from BOCSAR included the premises type in which the incident occurred (including residential freestanding, residential flats, business or commercial, outdoor or public place and road). This information could help investigate the influence on those exposed to ambient air temperatures, or accessing air-conditioning. The data also included age and gender of both the offender and the victim, as well as if the incident was related to domestic violence or alcohol use, all of which could provide interesting insights into the temperature-crime relationship.

4.2.3 Application of findings

This study has been purely empirical, however qualitative data collection such as surveys and interviews with police, hospital and welfare services that deal with assault could help answer the questions:

- Do hot temperatures cause an additional strain to their organisation or stakeholders?
- How is heat risk communicated to and within the organisation?
- Is temperature, or other climatic factors, currently embedded into organisation, systems? How effective is this? Are resources reallocated according? If not, which channels would be most effective to integrate this knowledge?
- What local, state or federal interventions (i.e. policies, plans) could better support their organisation in managing heat-crime relationships?
- Under a warming climate, how may these organisations adapt to potentially more crime? What are the triggers and thresholds to adapt to potential change?

Interviews with land use planners, councils and government agencies could identify how to respond to the crime-temperature relationship spatially. For example:

- What adaptation actions could be taken in areas most at risk from heat-related crime? And,
- How to better understand and manage the migration of people to cooler areas during a heatwave?

4.2.4 Projections under a warming climate

Some international studies have started to make projections around if and how a heat-crime relationship may change under a warming climate (Agnew, 2012; Anderson & DeLisi, 2011; Burke et al., 2015; Hsiang et al., 2013; Ranson, 2014). However, there has been limited plausible and testable studies into the causes and consequences of climate change on conflict (Gemenne et al., 2014). There is also confusion whether it is the effect of 'climate' or 'weather' that is being tested (Gleditsch, 2012). Further investigation into the impacts of this temperature increase on crime rates, drawing from a range of physical and social sciences would be beneficial in understanding the costs of climate change in Australia into the future.

4.3 Research exposure

The findings of this research have been presented at the following events:

- Australian Climate Change and Adaptation Research Network: Settlements and Infrastructure (ACCARNSI) Early Career Research Forum/Workshop. February 20 - 22 2017. Manly Vale, New South Wales. Forum abstract available in Appendix 2;
- 21st International Congress of Biometeorology. September 3-7, 2017. Durham, UK. Conference presentation, presented by principal supervisor, Associate Professor Paul Beggs. Conference abstract available in Appendix 3; and,
- The 29th Annual Scientific Conference of the International Society of Environmental Epidemiology. September 24-28, 2017. Sydney, Australia. Poster presentation, available in Appendix 4.

4.4 Conclusion

The main aims of this research were to determine if the common crimes of assault, theft and fraud was influenced by season and temperature within New South Wales, and if the relationship for assault differed between regions across the state. Firstly, the study found that both assault and theft are seasonal, and the number of monthly and daily incidents rise with an increase in temperature. Also that, as temperature increases, it is more likely that incidents of violent, rather than a nonviolent crime will rise. Secondly, that almost all Local Government Areas in New South Wales have higher assault rates in summer than winter, and that there is spatial difference in the relationship between temperature and assault rates, that is, a 'one size fits all' model can't easily be applied.

This is the first temporal and spatial study within the Australian climate, as well as being one of only several Southern Hemisphere studies. The results presented in this study are valuable for sectors such as law enforcement, health and social services.

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Appendices

Appendix 1: Key studies that model crime or a crime proxy using temperature

Reference	Time period	Location	Time unit	Spatial unit	Dependant variable	Statistical methods and controls	Sources of data	Findings
Anderson et al. (1997)	1950-1995	USA	Year	Country	Violent and property crime	Regression model. Controlled for auto regression parameters (to deal with auto correlated residuals), a linear year shift parameter, and an age distribution parameter	Annual temperature data for 50 largest cities. Crimes rates from Federal Bureau of Investigation	Study 1: Positive relation between temperature and serious and deadly assault. Property crime unrelated to annual average temperature. Study 2: Positive relation between number of hot days and magnitude of the summer effect. For property crime, the summer effect was unrelated to number of hot days
Anderson et al. (2000)	1950-1997	USA	Year	Country	Violent crime	A meta-analysis of significant studies to date. Then, laboratory heat effect studies; Experiment 1 using questionnaires followed by statistical analysis including t tests. Experiment 2+ using perceived comfort scales as well as physiological arousal. Regression analyses controlled for sex, linear temperature, and higher order temperature effects	Questionnaires, computer games and heart / stress tests	Significant increase or decrease in heat led to significant change in violent tendencies. Heat affects perceived hostility, no difference btw genders
Auliciems and DiBartolo (1995)	1992	Brisbane, Australia	Week	Municipality	Domestic violence	Descriptive statistics, daily Z-scores correlation coefficient trace. Controlled for full moon, holidays and day of week	Police calls relating to assault. Temperature, barometric pressure, humidity, wind speed, visibility	Significant associations were observed between calls and maximum air temperature during all seasons. At the weekly level, the temperature association was enhanced by barometric pressure, yielding a

							cloud and precipitation	regression which explained nearly 50% of the overall variability
Brunsdon et al. (2009)	Two year period	Unidentified region, UK	Hour	Municipality	Disorder and disturbance	Statistical analysis; test of association (Monte Carlo Kent-Joe statistic), kernel density, permutation test. If any association, found, then Visualisation techniques; map log-likelihood ratio, comap visualisation. Controlled for time of day, seasons,	Police callouts for an urban centre and its surrounding region (date, time, grid reference). Rainfall, wind speed, temperature	Temperature and humidity are significant on spatial patterning of incidents of disorder or disturbances. Rainfall, wind speed, and wind direction were found not to have a significant effect
Butke and Sheridan (2010)	1994-2004	Cleveland, USA	Season, day, hour	Municipality and sub city	Aggressive crime	Linear regression model. Controlled for season, time of day, day of week. Spatial analysis (Point density analysis, Wilcoxon rank sum test)	Cleveland Police Department for aggressive crimes. National Climatic Data Centre hourly weather data, temperature and dew point	Summer has highest aggressive crime, generally increases linearly as apparent temperature increases. Spatially, overall, the patterns of crime counts are minimally influenced by hotter weather
Cheatwood (1995)	1980, 1982, 1984, 1986	Baltimore, USA	Day	Municipality	Homicide	Simple Bivariate Correlations, multivariate analysis. Controlled for day of week, holidays	Baltimore City Police. National Climatic Data Centre, temperature, daily dew point, precipitation, sunshine, wind speed, snow, barometric pressure	The number of days in sequence where the discomfort point remains over 26ºC has the strongest effect on the probability of homicide
Coccia (2017)	2006-2013	191 countries	Annual	Countries	Homicide	Descriptive statistics, linear regression models, geospatial analysis. Controlled for latitude, income, Gross Domestic Product, population growth	Homicide rates from World Development Indicators, geographical climatic zones	Controlling for climate and other factors, socioeconomic inequality is positively associated to violent crime

Cohen and Krueger (2016)	2010	USA	Day	Field study	Survey result	Bivariate Correlations, logistic regressions. Controlled for race, age, gender, voting preference, education, income and ‘Obama margin’	Cooperative Congressional Election Survey, National Climatic Data Centre for average temperature	Average daily temperatures above 23ºC are associated with preferences for a stricter immigration policy as well as against permissive affirmative action policies
Cohn and Rotton (1997)	1987-1988	Minneapolis, USA	Hour	Municipality	Violent crime	Time series regression analysis. Controlled for seasons, weather variables, holidays	Police calls relating to assault. Ambient temperature, relative humidity, wind speed, visibility, and percentage sky cover	Relations between temperature and assaults are stronger during evening hours than during other hours of the day. Assaults declined after reaching a peak at moderately high temperatures
Cohn (1993)	1985, 1971, 1988	Minneapolis, USA	Hour	Municipality	Domestic violence	Multiple linear regression, moderator-variable regression analyses. Ordinary least squares analyses then iterative algorithm to obtain Prais-Winsten estimates of regression coefficients and their standard errors. Controlled for month, day of week, time of day, light, holidays and school terms	Police calls relating to rape and domestic violence. Temperature, wind speed, precipitation, fog, lunar cycles	Domestic violence is highly influenced by immediate temporal and weather variables such as time of day, day of week and ambient temperature. However, rape appears not to be as greatly affected by immediate situational conditions and contexts
Gamble and Hess (2012)	1993–1999	Dallas, USA	Day	Municipality	Violent crime	Ordinary least squares regression on rates, baseline regression analysis, time series piece-wise regression. Controlling for years, days of week, holidays, first day of month, season and daylight	Crime data by offence and postcode. Temperature, humidity	Daily mean ambient temperature is related to daily rates of violent crime with a positive and increasing relationship between temperature and aggravated crime that moderates beyond temperatures of 27ºC and then turns negative beyond 32ºC

Horrocks and Menclova (2011)	2000-2008	New Zealand	Day	Municipality (multiple)	Violent crime	Descriptive statistics, Im-Pesaran-Shin test, ordinary least squares (OLS). Controlled for population, unemployment, day of week, and linear time trend. Panel econometric techniques	Daily recorded incidents from 43 police districts. Temperature and precipitation	Temperature and precipitation have significant affect on violent crime. Temperature also affects property crime. At 32ºC violent crime starts decreasing.
Hu et al. (2017a)	2005-2014	Beijing, China	Day	Municipality	Violent and property crime	Linear regression analysis. Controlled for population.	Heat stress indices (discomfort, simplified wet-bulb globe temperature, the Humidex and temperature–humidity index for comfort).	Violent and nonviolent robbery rates significantly increase with heat stress in spring. The nonviolent robbery rates significantly increase with heat stress in summer. The influence of heat stress on violent robbery rate is more complicated and nonlinear
Hu et al. (2017b)	2009-2014	Tangshan, China	Month	Municipality	Violent and property crime	Simple regression analysis,	Monthly crime data, simplified wet bulb globe temperature	Strong positive correlations between temperature and violent and property crimes. Humidity positively correlated to rape and violent robbery
Jacob et al. (2007)	1995-2001	USA	Week	Municipality (multiple)	Violent and property crime	Regression. Correlation, lag rates. Controlled for day of week, month, season	FBI's National Incident Based Reporting System. Temperature, precipitation	Weather affects a broad range of criminal behaviours. Higher crime in one week is followed by less crime in subsequent weeks
Kenrick and MacFarlane (1986)	1985	USA	Day	Experimental / controlled on site	Road rage	Field test, step wise regression analysis. Controlled for air-conditioning	Primary data from counting horn use	A direct linear increase in horn honking with increasing temperature. Stronger results were obtains by those examining only those subjects who had their windows rolled down

Larrick et al. (2011)	1952-2009	USA	Day	Experimental / controlled on site	Retaliations in baseball	Generalised estimating equations. Controlled for attendance, games played and prior game conditions	Game data from 'Retrosheet' which included game details as well as game-time temperature	The probability of a pitcher hitting a batter increases sharply at high temperatures when more of the pitcher's teammates have been hit by the opposing team earlier in the game
Lester (1986)	1980	USA	Year	Municipality (multiple)	Homicide	Regression analysis. Controlled for temperature, precipitation	Temperature. Precipitation, latitude, longitude	State homicide rates varied gradually, rather than abruptly, with latitude
Linning et al. (2017)	2000-2006	British Columbia, Canada	Season	Municipality (multiple)	Violent and property crime	Dispersion tests, Negative binomial, Poisson count models. Controlled for trend, weather, and illumination variables	Assault, robbery, motor theft and break and enter from Crime Analysis System, Pacific Region (CASPR) for 8 cities. Temperature, precipitation, snow	Temperature changes impacted assault levels. Few weather variables affected the occurrence of robberies. Fluctuations in property crime were variable across the cities
Mares (2013)	1990-2009	St Louis, USA	Month	Municipality	Violent and property crime	Descriptive, time series. Controlled for unemployment, regional home sales and consumer price index	Police incident data. Climate data for temperature and precipitation	Monthly climatic conditions are correlated to most crime types, except rape
McLean (2007)	2002	Manchester, UK	Day	Municipality	Violent crime	Correlation and regression analyses. Controlled for day of the week	Cases at the St. Mary's Sexual Assault Referral Centre (including police and self-referred clients). Temperature, precipitation, wind speed, and hours of sunshine	Maximum temperature and hours of sunshine both had a statistically significant positive relationship with the number of sexual assaults committed in a day

Michel et al. (2016)	2008-2013	Baltimore, USA	Month	Municipality	Violent crime	Correlation coefficients, negative binomial regression. Controlled for month, weekend	Police reported incidents, trauma from hospital incidents. Temperature, precipitation, snowfall and snow depth	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
Mishra (2015)	2001-2013	India	Month	Country, municipality	Homicide	Simple statistical techniques. Controlled for population	Homicide rates from National Crime Record Bureau	Temperature affects the pattern of murder incidences. Poverty, urbanisation and income level do not affect the homicide significantly in unidirectional manner
Pakiam and Lim (1984)	1975	Singapore	Month	Country	Violent and property crime	Correlation, product moment correlation	Singapore police force incident data. Temperature, and 'index for comfort' including temperature, humidity and air speed	Crimes against the person are generally positively correlated with temperature and discomfort. The relationship between the weather parameters and various crimes against property varies from crime to crime
Ranson (2014)	1980-2009	USA	Month	Municipality (multiple)	Violent and property crime	Poisson regression approach with semi-parametric weather variables for maximum temperature bins. Regression. Controlled for lag time, socio economic, month, year	FBI's Uniform Crime Reporting data, National Climatic Data for temperature and precipitation	Temperature has a strong positive effect on criminal behaviour, with little evidence of lagged impacts. Linear relationship for aggressive crime, while non linear for property crime bending at 10^{o}C. Projections under a changing climate are additional incidents of crime
Rotton and Cohn (2001)	1987-1988	Minneapolis, USA	6 hour intervals	Municipality	Domestic violence	A reanalysis of Cohn (1993). Moderator-variable regression analyses. Controlled for time,	Police call outs regarding domestic violence. Ambient temperature, relative	Temporal variables explained 75% of the variance in calls for service, with a downturn in

						day, season, holidays and weather variables	humidity, wind speed and sky cover	violence at high temperatures (>28ºC)
Rotton and Cohn (2004)	1994-1996	Dallas, USA	3 hourly	Municipality	Assault	Builds on Cohn and Rotton (1997) and (Rotton & Cohn, 2000a). Multivariate analysis of covariance, controlled for holidays, time of day, day of week and season	Police calls for assault including place of offence. National climatic Data Centre; dry bulb temperature, relative humidity, wind speed, barometric pressure	Assaults in climate-controlled settings were a linear function of temperature, whereas assaults in settings that probably lacked climate control declined after peaking at moderately high temperatures
Schinasi and Hamra (2017)	2006 - 2015	Philadelphia, PA	Daily	Municipality	Violent crime	Generalised additive models, quasi-Poisson distribution. Adjusted for day of week, holiday, long tern trends, seasonality	Crime data for police department, hourly temperature and dew point data	Disorderly conduct and violent crimes are highest when temperatures are comfortable, especially during cold months
Williams et al. (2015)	1994 - 2009	New Zealand	Day	Municipality (multiple)	Assault	Generalised linear mixed models, Poisson distribution and log link. Controlled for population size, ethnicity and age	Recorded assault data from the NZ Police, and assault hospitalisation data from the Ministry of Health. Grid meteorological data	Geographical, seasonal, and irregular daily variation in temperature were all positively related to the incidence of assault, although only the effect of irregular variation in temperature was robust to controls for plausible confounders
Wilson and Thomas (2017)	1995-2007	Darwin, Australia	Unknown	State	Assault	Retrospective Chart Analysis. Statistical methods not stated	Facial trauma medical records, Bureau of Meteorology including temperature, rain, sunlight and humidity	Statistically significant association between weather variables and facial trauma rates

Appendix 2: Abstract from Forum presentation at the Australian Climate Change and Adaptation Research Network: Settlements and Infrastructure (ACCARNSI) Early Career Research Thirteenth National Forum and Workshop. February 20 - 22 2017. Manly Vale, New South Wales, Australia

Heather STEVENS
Macquarie University, NSW

DO HEAT WAVES CAUSE HOT TEMPERS? HOW EXTREME HEAT IMPACTS CRIME IN NSW AND WHAT THIS MEANS UNDER A CHANGING CLIMATE

Heather Stevens

Abstract:
Heat waves are anecdotally linked to a range of anti-social behaviours such as domestic violence, alcohol abuse, road rage and suicide. The correlation between heat and violence is so entrenched that it has become part of our language – hotheads, simmering anger or to get hot under the color. However, is this true? Although some preliminary international studies have made connections, there has not been as yet any significant assessment of heat crime in Australia. And, if there is a link between heat waves and crime, what does this mean in a climate that is getting hotter? This study assesses the relationships between extreme heat and crime, and identifies which crimes and conditions matter. The research draws on big data sets like the Bureau of Metrology and the NSW Bureau of Crime Statistics to address questions such as:

* Is there a relationship between extreme heat and crime, and if so, which ones?

* Is there a difference between urban or rural areas, and socio-econonic regions?

* How does the intensity, frequency and distribution of heat waves impact crime? Is the relationship between crime and heat linear (i.e. it increases as does temperature) or is it non linear (i.e. are there peaks and then plateau's)?

* What does this mean under a warming climate?

* What are the adaptation actions within urban planning, governance, policy etc to reduce the future impacts of heat related crime?

This findings of this work will be of interest to those within public health, environmental policy, crime prevention and national security.

Appendix 3: Abstract from conference presentation at the 21st International Congress of Biometeorology, September 3-7, 2017, Durham, UK. Conference handbook, pg. 64. Presentation given by Associate Professor Paul Beggs, Principal Supervisor.

9B.1

Hot under the collar – the relationship between temperature and crime in Australia

Heather R. Stevens, Paul J. Beggs, Petra L. Graham (Macquarie University, Australia)

Heat waves are anecdotally linked to a range of anti-social behaviours such as domestic violence, alcohol abuse, and road rage. The association between heat and violence is so entrenched that it has become part of the English language – a hothead, simmering anger, or to be hot under the collar. However, does extreme heat cause such behaviours? Although some international studies have made connections between temperature and crime and/or aggression, very little research has been done within the unique Australian climate. The aim of this study is to investigate the relationships between temperature and crime in New South Wales (NSW), Australia, as well as how age and gender influence the relationship. The study uses statistical modelling to examine seasonal, monthly, and daily relationships between temperature and recorded crime rates, controlling for confounding factors. The study looks at both crimes against the person (e.g., homicide, assault) as well as crimes against property (e.g., theft, vandalism). Data is drawn from the Australian Bureau of Meteorology and the NSW Bureau of Crime Statistics and Research over a 30-year period for the whole of NSW as well as metropolitan and regional areas. Preliminary results show that there is both a seasonal and daily correlation between temperature and most categories of crime. For example, incidents of assault in NSW consistently peak in summer (often with a double peak, in December and March) and are at a minimum in winter. The study also considers the various theories that may explain these relationships. The findings of this novel study give insights into how to better understand and manage crime. The results also become more pressing when considering a future warming world.

Appendix 4: Poster Presentation at the 29th Annual Scientific Conference of the International Society of Environmental Epidemiology, 24-28 September, 2017, Sydney, Australia.

MACQUARIE University SYDNEY·AUSTRALIA

Relationship between temperature and assault in NSW

Heather R. Stevens[1], Paul J. Beggs[1], and Petra L. Graham[2]
[1]Department of Environmental Sciences, Macquarie University
[2]Department of Statistics, Macquarie University

ISEE17 24-28 September 2017, Sydney Australia

DOES HOT WEATHER CAUSE AGGRESSION?

Numerous Northern Hemisphere studies have looked at the impact of temperature on aggressive crimes (Cohen and Krueger; Michel et al.; Ranson).

Studies tend to be:
- **Temporal:** investigating relationships over time;
- **Spatial:** investigating how relationships differ geographically;
- **Experimental:** controlled physiological or behavioural.

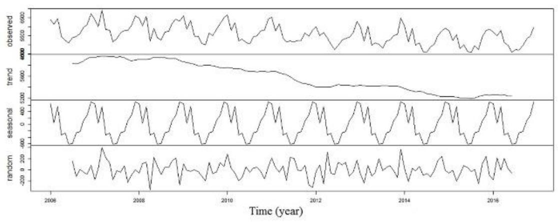
To date, very little has been done within the Australian climate.

STUDY AIM

Assess the relationship between temperature and assault in NSW and Greater Sydney

Specifically:
- Model the seasonal and monthly significance of assault;
- Visualise relationship of daily assault and temperature;
- Model and map spatial differences across NSW.

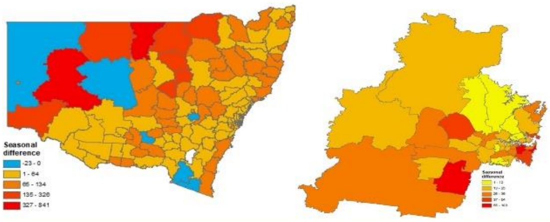
TEMPORAL: ASSAULT NSW 2006 - 2016



- Decomposition plots show clear seasonal trend with summer double peak.
- Linear regression model found summer had 18% more incidents of assault on average than winter.
- Time series model found 1°C increase in temperature had 2.2% more incidents of assault.

DIFFERENCE BETWEEN SUMMER / WINTER ASSAULT RATES

The majority of NSW (left) and all of the Greater Sydney Region (right) experienced on average higher rates of assault during summer than winter (blue = decrease).



IS IT HEAT? OR ARE THERE ALTERNATIVE EXPLANATIONS?

The Routine Activity Theory (Cohen and Felson) proposes that warmer weather creates behavioural change and greater opportunity to commit crime, i.e., increased socialisation, alcohol consumption, holidays and travel. **This may support why assault shows higher rates during summer and holiday months.**

The General Affect Theory (Anderson et al.) proposes an interaction between biological and psychological processes to explain aggression. **This may support why, when controlling for season, holidays etc., temperature against assault remains significant.**

IMPLICATIONS

- This study places forecasting of assault based on temperature on firm empirical footing.
- This knowledge could allow for policing, hospitals etc. to better allocate resources.
- Spatial differences support local responses.
- Assault in a warming climate?

REFERENCES

Anderson, C. A., Anderson, K. B., Dorr, N., DeNeve, K. M., & Flanagan, M. (2000). Temperature and aggression. *Advances in Experimental Social Psychology, 32*, 63-133. Cohen, A., & Krueger, J. (2016). Rising mercury, rising hostility: How heat affects survey response. *Field Methods, 28*(2), 133-152. Cohen, L. E., & Felson, M. (1979). Social change and crime rate trends: A routine activity approach. *American Sociological Review, 44*(August), 588-608. Michel, S. J., Wang, H., Selvarajah, S., Canner, J. K., Murrill, M., Chi, A., Efron, D. T., & Schneider, E. B. (2016). Investigating the relationship between weather and violence in Baltimore, Maryland, USA. *Injury, 47*(1), 272-276. Ranson, M. (2014). Crime, weather, and climate change. *Journal of Environmental Economics and Management, 67*(3), 274-302.

Conference reference: 5688

Appendix 5: Ethics approval

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(Research)

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MACQUARIE University
SYDNEY·AUSTRALIA

5 May 2017

Dear Associate Professor Beggs,

Reference No: 5201700382

Title: *Investigation of the relationship between weather/climate and crime in NSW.*

Thank you for submitting the above application for ethical and scientific review. Your application was considered by the Macquarie University Human Research Ethics Committee (HREC (Human Sciences & Humanities)).

I am pleased to advise that ethical and scientific approval has been granted for this project to be conducted by:

- Macquarie University

This research meets the requirements set out in the *National Statement on Ethical Conduct in Human Research* (2007 – Updated May 2015) (the *National Statement*).

Standard Conditions of Approval:

1. Continuing compliance with the requirements of the *National Statement*, which is available at the following website:

http://www.nhmrc.gov.au/book/national-statement-ethical-conduct-human-research

2. This approval is valid for five (5) years, subject to the submission of annual reports. Please submit your reports on the anniversary of the approval for this protocol.

3. All adverse events, including events which might affect the continued ethical and scientific acceptability of the project, must be reported to the HREC within 72 hours.

4. Proposed changes to the protocol and associated documents must be submitted to the Committee for approval before implementation.

It is the responsibility of the Chief investigator to retain a copy of all documentation related to this project and to forward a copy of this approval letter to all personnel listed on the project.

Should you have any queries regarding your project, please contact the Ethics Secretariat on 9850 4194 or by email ethics.secretariat@mq.edu.au

The HREC (Human Sciences and Humanities) Terms of Reference and Standard Operating Procedures are available from the Research Office website at:

http://www.research.mq.edu.au/for/researchers/how_to_obtain_ethics_approval/human_research_ethics

The HREC (Human Sciences and Humanities) wishes you every success in your research.

Yours sincerely

Dr Karolyn White
Director, Research Ethics & Integrity,
Chair, Human Research Ethics Committee (Human Sciences and Humanities)

This HREC is constituted and operates in accordance with the National Health and Medical Research Council's (NHMRC) *National Statement on Ethical Conduct in Human Research* (2007) and the *CPMP/ICH Note for Guidance on Good Clinical Practice.*

Details of this approval are as follows:

Approval Date: 28 April 2017

The following documentation has been reviewed and approved by the HREC (Human Sciences & Humanities):

Documents reviewed	Version no.	Date
Macquarie University Ethics Application Form		Received 10/03/2017
Macquarie University Appendix D: Privacy and Access to Personal Information	1	Received 10/03/2017

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