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Impact of climate variability and change on crime rates in Tangshan, China

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Abstract: Studies examining the relation between climate and human conflict often focus on the role of temperature and have diverging views on the significance of other climatic variables. Using a 6-year (from 2009 to 2014) dataset of crime statistics collected in a medium size city of Tangshan in China, we find strong, positive correlations between temperature and both violent and property crimes. In addition, relative humidity is also positively correlated with Rape and Minimal Violent Robbery (MVR). The seasonal cycle is a significant factor that induces good correlations between crime rates and climatic variables, which can be reasonably explained by the Routine Activity theory. We also show that the combined impacts of temperature and relative humidity on crime rates can be reasonably captured by traditional heat stress indices. Using an ensemble of CMIP5 global climate change simulations, we estimate that at the end of the 21st century the rates of Rape (violent crime) and MVR (property crime) in Tangshan will increase by $9.5 \pm 5.3\%$ and $2.6 \pm 2.1\%$, respectively, under the highest emission scenario (Representative Concentration Pathway 8.5). The gross domestic product (GDP) is also shown to be significantly correlated with MVR rates and the regression results are strongly impacted by whether GDP is considered or not.

Keywords: climate, crime rate, temperature, relative humidity, heat stress, seasonality, GDP

1 Introduction

A growing number of research studies have demonstrated the impact of climate on human

26 conflict, including large-scale conflict (Bernauer et al., 2012; Burke et al., 2009; Hsiang et al., 2013;
27 Hsiang et al., 2011; O'Loughlin et al., 2012; Scheffran et al., 2012; Tol and Wagner, 2010; Zhang et
28 al., 2011) (e.g., civil conflict, warfare, and human crisis) and crime (Barnett and Adger, 2007;
29 Brunsdon et al., 2009; Horrocks and Menclova, 2011; Mares, 2013; Mehluma et al., 2006; Ranson,
30 2014; Shi et al., 2015; Skudder et al., 2016). A recent global synthesis work assembled and analyzed
31 60 previous quantitative studies and found out that 1σ (where σ denotes the standard deviation)
32 change in the climate toward warmer temperature or more extreme rainfall increases the frequency
33 of intergroup conflict by 14% and interpersonal violence by 4% (Hsiang et al., 2013). Another recent
34 study pointed out that each degree Celsius increase in the annual mean temperature is associated
35 with on average nearly 6% increase in homicides (Mares and Moffett, 2016).

36 Previous work investigating the influence of climate on crime rates often focused on the role of
37 temperature. For example, a number of studies pointed out that temperature had a significant effect
38 on crime (Barnett and Adger, 2007; Brunsdon et al., 2009; Horrocks and Menclova, 2011; Mares,
39 2013), and was often positively correlated with the number of crime incidents (Ranson, 2014).
40 Rainfall and droughts have been also considered in the literature but their impacts are primarily on
41 property crimes (Mehluma et al., 2006) and are often seen in low-income communities (Miguel,
42 2005). Prior criminological work on other climatic variables (humidity, wind speed, etc.) has largely
43 been fruitless with contradicting results (Cohn and Rotton, 1997; James and Corcoran, 1990; Rotton
44 and Cohn, 2001; Rotton and Cohn, 2004). For instance, a recent study examining the effect of
45 relative humidity pointed out that relative humidity had a significant and positive correlation with
46 crime rates (Mishra, 2014). Their results were nonetheless contradictory to another study (Gamble
47 and Hess, 2012) showing that the correlation coefficient between relative humidity and crime rates
48 was extremely small with a low significance level. As a result, whether climatic variables other than

49 temperature such as relative humidity are also correlated with crime rates remains an open question.

50 Why do weather or climate variables affect crimes? The Routine Activity (RA) theory proposed
51 by [Cohen and Felson \(1979\)](#) offers one perspective. In the RA theory, there are three necessary
52 conditions for committing a crime: (1) a potential offender with the capacity to commit a crime; (2) a
53 suitable target or victim; and finally (3) the absence of guardians capable of protecting targets and
54 victims. The likely offender may be anyone with a motive to commit a crime and with the capacity
55 to do so ([Felson and Cohen, 1980](#)). [Cohen and Felson \(1979\)](#) used the term “motivated offender” but
56 in later work ([Felson and Cohen, 1980](#)) they avoided the term “motivated”, as what they considered
57 relevant was not the disposition or motivation to commit a crime but rather the physical factors that
58 made it possible for a person to be involved in a crime. The suitable target is a person or property
59 that may be threatened by an offender. The probability that a target is selected is influenced by the
60 value, inertia (physical aspects of the person or good), visibility (exposure of targets), and access
61 ([Cohen and Felson, 1979](#); [Felson and Clarke, 1998](#)). The third and final element described in the RA
62 theory is the absence of a capable guardian who can intervene to stop or impede a crime ([Cohen &
63 Felson, 1979](#)). A guardian is defined as someone in whose presence the crime is not committed, and
64 whose absence makes it more probable ([Felson, 1995](#)). In the framework of RA, higher but not
65 extreme temperature is likely to increase mobility and social interaction (e.g., in summer), increasing
66 the likelihood of a suitable target occurring and also present more opportunities for crimes to occur.

67 The RA theory has been widely used in crime research to explain the seasonality, the spatial and
68 temporal distributions of crime. For instance, [Landau and Fridman \(1993\)](#) used RA to explain the
69 seasonality of homicide and robbery in Israel, considering crime as a function of three main elements:
70 motivated offenders, suitable targets, and the absence of guardians; [Andresen and Malleson \(2013\)](#)
71 investigated the existence of seasonality in crime and used the RA theory to explain the spatial

72 variations of certain crimes; [Drawve et al. \(2014\)](#) extended the RA theory to understanding
73 variations in the likelihood of an offender being arrested; [Pereira et al. \(2016\)](#) investigated the
74 temporal variations (seasons, months, days of week, and periods of day) of homicide in Recife,
75 Brazil, a city with a tropical climate, and employed the RA theory as one of the theoretical
76 arguments.

77 In addition to RA, other theories also exist and offer different perspectives. For example, the
78 General Affect (GA) model proposes that higher temperatures facilitate effective aggression ([Cohn
79 and Rotton, 2000](#)). The Negative Affect Escape (NAE) model suggests that human aggression
80 increases with temperature because of increases in discomfort, but only up to a certain point beyond
81 which the relationship will become negative ([Bell, 1992](#)). Based on the GA model and the NAE
82 model, heat stress may be a key to explaining the relation between the climate and crime rates. As
83 the heat stress increases, the level of discomfort increases, which leads to more crimes. Even in the
84 framework of RA, whether a crime occurs or not is strongly tied to the offender's individual-level
85 motivation and incentive, which may be affected by heat stress. Numerous psychological studies
86 showed that relative humidity could strongly affect human comfort. In fact, many heat stress indices
87 include relative humidity ([ACSM, 1984](#); [Buzan et al., 2015](#); [Dunne et al., 2013](#); [Fischer et al., 2012](#);
88 [Ingram, 1965](#); [Kovats and Hajat, 2008](#); [Masterson and Richardson, 1979](#); [Oleson et al., 2015](#); [Pal
89 and Eltahir, 2015](#); [Sherwood and Huber, 2010](#); [Steadman, 1984](#); [Thom, 1959](#)). It is thus not
90 unreasonable to expect that relative humidity also affects crime but it is still unclear whether
91 traditional heat stress indices could capture their impacts on crime.

92 To examine the relation between climate variables and crime rates, monthly records of six
93 different types of crimes (i.e., Homicide, Assault, Rape, Robbery, Burglary, and Minima Violent
94 Robbery) and two climatic variables (i.e., temperature, and relative humidity) collected in Tangshan,

95 China during 2009 to 2014 are used. Annual GDP data provided by Tangshan government are also
96 used. Tangshan, with a population of 7.6 million and area of 13,472 km², is an industrial city in
97 northeastern China, which is approximately 150 kilometers southeast of Beijing and the center of
98 city is located at 39.62 N, 118.18 E. The city is challenged with a rising number of crimes in recent
99 years with more than 170, 000 crime incidents between 2009 and 2014 but is a less studied area in
100 the literature. Tangshan has a monsoon-influenced, humid continental climate with cold and dry
101 winters and hot and rainy summers. The annual mean temperature of Tangshan is 11.5 °C, with
102 monthly average temperatures of -5.1 °C and 25.7 °C in January and July, respectively. About 60%
103 of its annual precipitation (about 610 mm) falls in July and August.

104 In this paper, we first investigate the separate impacts of temperature and relative humidity on
105 six types of crimes by time series analysis and simple regression. Then the combined impacts of
106 temperature and relative humidity on crime rates are studied using five traditional heat stress indices.
107 Finally, using an ensemble global climate change simulations from Coupled Model Intercomparison
108 Project Phase 5 (CMIP5), we investigate climate-induced changes in crime rates in Tangshan in the
109 late 21st century under three different emission scenarios (Representative Concentration Pathways).

110 **2 Methods**

111 **2.1 Data and regression analysis**

112 The analysis for this paper is based on a 6-year (from 2009 to 2014) dataset of monthly crime
113 numbers provided by the Municipal Public Safety Bureau of Tangshan, China from the crime
114 statistics database. This dataset includes 3 categories, namely, “Cases reported”, “Cases confirmed”,
115 and “Cases solved”. Cases reported is collected from the 110 calls data (like 911 calls data in the
116 US), but this is a voluntary report and the crime types cannot always be confirmed. Thus, the data
117 used in this paper are Cases confirmed, which can provide more accurate crime counts. All data used

118 in this paper are raw data without any modification. The data used in this study have some
119 limitations. For example, aggravated and simple assaults are not separated. Simple assaults are often
120 considered sensitive to any reporting biases. For instance, simple assaults get reported at higher rates
121 during pleasant months because more people are out, witnessing crimes and calling police. This is
122 also true in China. What is unique about Chinese cities is that the population density is often very
123 large. As a result, there is enough number of people witnessing any assault (which is always
124 considered as an unusual incident) and calling to police even in winter. Another limitation is that raw
125 crime counts for some types of crime (e.g. Homicide) are very low, and it may lead to some
126 problems such as over dispersion in our statistical analysis. To avoid over dispersion, crime rates
127 (crime incidents/ 10^6 people) are used rather than the raw crime counts. An example of the data
128 format is shown in [Table A1](#).

129 In total, six different crime types are included, namely, Homicide, Assault, Rape, Robbery,
130 Burglary and Minimal Violent Robbery (MVR), all of which are common crime types in China. Here
131 Assault includes both aggravated assault and simple assault. Robbery is considered as a violent
132 crime. Minimal Violent Robbery is a unique type of property crime in China, which is similar to
133 Robbery but with minimal even no violence. That is, Robbery is to obtain properties by means of
134 violence; while MVR is to obtain properties of a person who is unaware. As an example, if someone
135 steals a necklace from a lady when the lady is unaware throughout the whole incident, it is reported
136 as stealing; if someone takes the necklace away from the lady's neck when she is unaware, but at the
137 instant the lady realizes that someone is taking her necklace away but could not stop it, this is
138 reported as Minimal Violent Robbery; if someone obtains the necklace from the lady by violence, it
139 is reported as (violent) Robbery.

140 In order to examine whether there are linear relationships between crime rates and climate

141 variables, simple regression analysis is conducted using the following equation,

$$142 \quad A = \alpha_0 + \alpha_1 B + \varepsilon \quad (1)$$

143 where A represent the crime rates (crime incidents/ 10^6 people), B represents the value of climate
 144 variables, α_0 and α_1 are parameters, and ε is an error term. In this paper, climate variables include
 145 temperature and relative humidity or indices formulated by combining them. Here α_0 represents the
 146 socio-economical influence on crime. It has been long recognized that crime rates are strongly
 147 affected by socio-economic factors. For instance, increases in gross domestic product (GDP) may be
 148 accompanied by increases in crime rates. In the same time, increases in the number of police officers
 149 and security measures may reduce crime incidents. In this paper, we recognize the importance of
 150 socio-economic factors and assume that α_0 is either a constant or a linear function of GDP ($\alpha_0 = \lambda$
 151 GDP).

152 To examine the relationship between human comfort and crime rates, five heat stress indices are
 153 conducted as shown in [Table 1](#). All heat stress indices considered in our study combine the effects of
 154 temperature and relative humidity. Only the results with the Simplified Wet Bulb Globe Temperature
 155 (sWBGT) are discussed here since results with other heat stress indices are very similar.

156 **Table 1 Heat stress indices**

Indices	Descriptions
Simplified Wet Bulb Globe Temperature (sWBGT) (ACSM, 1984)	$sWBGT = 0.56T + 0.393e + 3.94$
Humidity Index (HUMIDEX) (Masterson and Richardson, 1979)	$HUMIDEX = T + 0.56(e - 10)$
Temperature Humidity Index for Comfort (THIC) (Ingram, 1965)	$THIC = 0.72T_w + 0.72T + 40.6^*$
Temperature Humidity Index for Physiology (THIP) (Ingram, 1965)	$THIP = 0.63T_w + 1.17T + 32$
Discomfort Index (DI) (Thom, 1959)	$DI = 0.5T_w + 0.5T$

157 * T_w is the wet bulb temperature ($^{\circ}C$) ([Ingram, 1965](#)) and e is the water vapor pressure that can be calculated from T
 158 and RH at a given pressure ([Buzan et al., 2015](#)).

159 2.2 Future projections

160 To estimate future changes in crime rates in Tangshan at the end of the century (2094–2099)
161 due to changes in climatic variables, monthly data from 13 different CMIP5 models (listed in [Table](#)
162 [2](#)) are used in this paper. The use of CMIP5 model data in our study is justified by the fact that the
163 size of Tangshan is comparable to the spatial resolution of these global climate models ($\sim 100 \times$
164 100 km^2). For each model, three representative concentration pathways (RCP2.6, RCP4.5 and
165 RCP8.5), which represent different emission scenarios and thus socio-economic changes, are
166 considered.

167 First, we calculate changes in climate variables between the beginning of the century (2009 –
168 2014) and the end of the century (2094 – 2099) by

$$169 \quad \Delta B_i = B_i^{2094-2099} - B_i^{2009-2014} \quad (2)$$

170 where ΔB_i represents changes in the climate variable or the heat stress index B in the i^{th} month. By
171 doing so, we also remove the mean bias in the climate simulations. Second, we compute the change
172 in crime rates for every type of crime based on

$$173 \quad \Delta A_{ji} = \alpha_{1j} \Delta B_i \quad (3)$$

174 where ΔA_{ji} represents the change in crime rate for the j^{th} type of crime in the i^{th} month. α_{1j} is the
175 parameter obtained from regression analysis. Third, we take the mean of 12 months to obtain the
176 change of crime numbers ΔA for every crime and every model:

$$177 \quad \Delta A_j = \frac{\sum_{i=1}^n \Delta A_{ji}}{n} \quad (4)$$

178 where ΔA_j represent the mean change of the j^{th} type of crime and n is the number of months in the
179 period. It is stressed that ΔA refers to changes in crime rates due to changes in climatic variables
180 and changes in crime rates due to socio-economic changes are not considered here. Finally, we

181 calculate the ensemble mean of the j^{th} type of crime and also the standard deviation across 13
 182 models.

183 **Table 2 CMIP5 models.**

Model abbreviation	Institution
CESM1-CAM	National Center for Atmospheric Research, USA
FGOALS-G2.0	LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences
GFDL-CM3	NOAA Geophysical Fluid Dynamics Laboratory, USA
GFDL-ESM2G	As in GFDL-CM3
GFDL-ESM2M	As in GFDL-CM3
HadGEM2-AO	National Institute of Meteorological Research/Korea Meteorological Administration, Korea
HadGEM2-ES	Met Office Hadley Centre, UK
IPSL-CM5A-MR	Institute Pierre Simon Laplace, France
MIROC5	Model for Interdisciplinary Research on Climate, Japan
MIROC-ESM	As in MIROC5
MIROC-ESM-CHEM	As in MIROC5
MPI-ESM-LR	Max Planck Institute for Meteorology, Germany
MPI-ESM-MR	As in MPI-ESM-LR

184 **3 Results and discussions**

185 **3.1 Simple regression analysis**

186 First, the temporal variations of climatic variables and crime rates during 2009 to 2014 are
 187 shown in [Fig.1](#). From this figure, we can see that temperature (T) shows clear seasonal cycles during
 188 the study period; relative humidity (RH) also shows seasonal cycles but with some irregularities. No
 189 clear long-term trend is detected for T but a slightly increasing trend is observed for RH. Most crime
 190 types (except Homicide) have generally increasing trends. Moreover, for Rape and Minimal Violent
 191 Robbery (MVR), clear seasonal cycles are also seen, similar to those of T and RH.

192 Next, simple regression analysis is conducted to examine the relation between monthly crime
 193 rates and monthly mean temperature (T) and relative humidity (RH) (see Methods). Lagged impacts
 194 on crime rates are not considered in this paper since they have been shown to be insignificant by a
 195 previous study ([Ranson, 2014](#)). The six crime types are broadly separated into two major categories:

196 property crimes (i.e., Burglary, and MVR) and violent crimes (i.e., Murder, Assault, Rape and
197 Robbery). [Table 3](#) shows a strong relationship between temperature and MVR (property crime, $R^2 =$
198 0.51), which can be also seen from [Fig. 1](#). This result suggests that increases in certain property
199 crimes are associated with increases in the temperature.

200 The effect of temperature on property crimes such as MVR may be interpreted by the RA theory.
201 Higher but not extreme temperature is more likely to increase mobility and social interaction,
202 increasing the likelihood of a suitable target occurring and also present more opportunities for
203 property crimes to occur. However, it is pointed out that police presence may also be associated with
204 temperature or other weather conditions ([Horrocks and Menclova, 2011](#)), e.g. in warmer days, the
205 increasing social interaction may also increase the police presence, which may result in fewer crimes
206 as criminals may realize the increased probability of being caught.

207 On the other hand, as shown in [Table 3](#), the R^2 value between Burglary and temperature is only
208 0.09, suggesting that Burglary is not strongly associated with temperature. The RA theory also
209 explains why Burglary, which happens indoors, is not well correlated with temperature. Burglary
210 offenders are more likely to commit crimes when people are outside and where the security level is
211 low. Thus, most of the Burglary crimes in China occur at 7~9 am when people just go out to work in
212 weekdays or at 0~2 am when people are in deep sleep ([Chen et al., 2009](#)), and are not strongly
213 associated with the weather conditions. The fact that temperature is not associated with Burglary is
214 consistent with previous studies ([Chen et al., 2011](#); [Ranson, 2014](#)).

215 For violent crimes, the R^2 values between Rape and temperature is larger than 0.4, suggesting
216 that higher Rape rates are significantly associated with higher temperatures. This is consistent with
217 [Fig.1](#) as well as many previous studies ([Barnett and Adger, 2007](#); [Horrocks and Menclova, 2011](#);
218 [Ranson, 2014](#)). The effect of temperature on Rape may also be interpreted by RA. For instance,

219 Rape shows a distinct seasonal cycle that correlates with the seasonal cycle of temperature since in
220 summers people are more likely to be outside, come into contact with one another, and go back
221 home late, thereby presenting more opportunity for Rape to occur. In the meantime, one can argue
222 that heat stress may also contribute to, at least part of, the relation between Rape and temperature.
223 According to the GA model, higher temperatures increase human discomfort and may therefore lead
224 to crime occurrence.

225 However, the relations between temperature and violent crimes cannot be always explained by
226 these theories. For example, [Table 3](#) suggests a less significant relationship between temperature and
227 violent Robbery (R^2 is 0.10). This is consistent with our recent study examining the difference
228 between Robbery and MVR in Beijing, China ([Hu et al., 2017](#)). Based on the GA and NAE models,
229 when human discomfort is beyond the threshold where the criminal's motivation to escape
230 uncomfortable situations outweighs the motivation to be aggressive, violent Robbery will no longer
231 increase or even decrease with increasing heat stress ([Hu et al., 2017](#)). So affected by opportunities,
232 targets, guardians, and human comfort, the relation between violent Robbery and temperature is
233 more complex and less significant than the relation between MVR and temperature ([Hu et al., 2017](#)).

234 In summary, the correlations between several types of property and violent crimes and
235 temperature are good due to the seasonality in both crime and temperature data, which can be
236 reasonably explained by the RA theory. This does not necessarily mean that heat stress does not play
237 a role. Even in the framework of RA, whether a crime occurs or not is strongly tied to the offender's
238 motivation and incentive. In some cases the individual-level motivation and incentive may have little
239 to do with temperature (and other climate variables), but in other cases they may be affected by
240 temperature (and other climate variables) due to for example human discomfort. Nonetheless, even if
241 heat stress plays a role, it is extremely difficult to separate the role of temperature in terms of

242 inducing human discomfort and thus crime from the role of temperature in terms of increasing the
243 probability of suitable targets occurrence in the RA framework.

244 The relations between RH and crime rates are quite different and interesting. Rape and MVR
245 are significantly correlated with RH ($R^2 > 0.1$ and $p < 0.05$). Robbery and Burglary are also
246 significantly associated with RH but the R^2 values are small. From the results, we can infer that RH
247 is associated with both violent (such as Rape) and property (such as MVR) crimes, which is again
248 largely due to the seasonality of RH and that of crime rates. It is pointed out that the seasonal cycle
249 of RH is not as distinct as that of T, which may be the reason that all of R^2 values between RH and
250 crime rates are much lower than those between T and crime rates, and most of relations between
251 crimes (i.e. Homicide, Assault, Robbery and Burglary) and RH are not significant. One can argue
252 that the good correlations between RH and Rape/MVR, which largely come from the seasonality in
253 both crime and RH data, can be also explained by the RA theory. In summer, the likelihood of
254 suitable targets increases thereby presenting more opportunities for crimes and in the meantime, the
255 RH is also high. On the other hand, one can also argue that higher RH leads to reduced human
256 comfort and may motivate more crimes (similar to the GA model).

257 Based on time series analysis and regression results and using $R^2 = 0.16$ (which corresponds to
258 a correlation coefficient of 0.4) as a threshold, we conclude that Rape and MVR are significantly
259 associated with both temperature and relative humidity. The correlations between climate variables
260 and other types of crimes are less robust.



261

262 **Fig.1 Temporal distributions of climatic variables and crime rates during 2009 to 2014.**

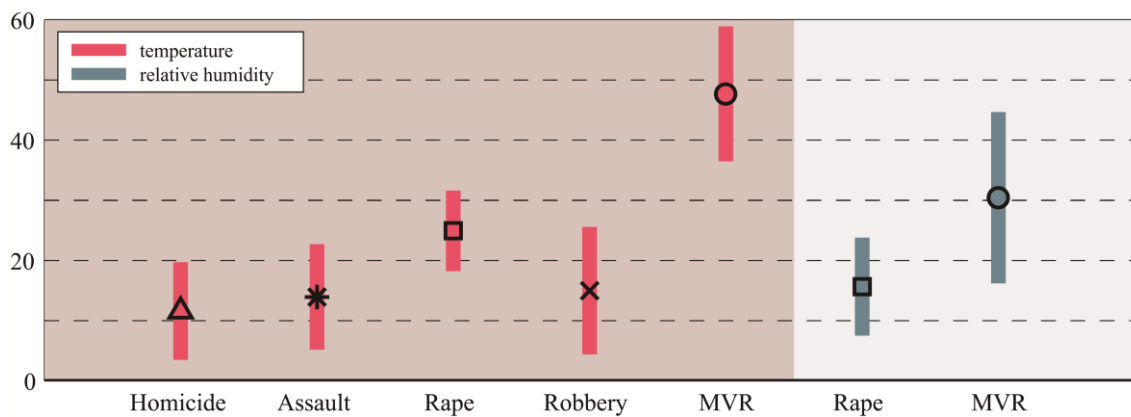
263 To evaluate whether changes in temperature and relative humidity will lead to significant
 264 changes in the crime rates, an empirical estimate is used here following the global synthesis study
 265 (Hsiang et al., 2013) mentioned earlier. That is, if a 1σ (where σ denotes the standard deviation)
 266 increase in a climate variable leads to a change in the crime rate greater than 10% (relative to its

267 mean), then it is considered significant. As shown in Fig. 2, we can see that for each 1 σ increase in T,
 268 increases in the number of Rape and MVR are larger than 20%, especially MVR which experiences
 269 an increase of over 45%. For each 1 σ increase in relative humidity, the increase in MVR is larger
 270 than 20%. These results are broadly consistent with the simple regression results in Table 3.

271 **Table 3 Simple regression analysis results (R^2) between crime rates and temperature (T, °C) and relative**
 272 **humidity (RH, %).**

	Homicide	Assault	Rape	Robbery	Burglary	MVR
T	<u>0.10*</u>	<u>0.13*</u>	<u>0.44*</u>	<u>0.10*</u>	0.09*	<u>0.51*</u>
RH	0.02	0.05	<u>0.17*</u>	0.00	0.00	<u>0.21*</u>

273 * denotes a significance level lower than 0.05



274
 275 **Fig.2 Impacts of temperature (T, °C) and relative humidity (RH, %) on crime rates.** Each marker represents the
 276 estimated impact of a 1 σ increase in a climate variable, expressed as a percentage change in the outcome variable
 277 relative to its mean. Whiskers represent the 95% CI (confidence interval) for this estimate. The results are mainly
 278 determined by the parameter α_1 in Eq. 1 and its 95% confidence interval.

279 3.2 Heat stress indices

280 We further test whether traditional heat stress indices (see Table 1), including Simplified Wet
 281 Bulb Globe Temperature (sWBGT), Humidity Index (HUMIDEX), Temperature Humidity Index for
 282 Comfort (THIC), Temperature Humidity Index for Physiology (THIP) and Discomfort Index (DI),
 283 can capture the climate influence on crime. Results indicate that the R^2 values for heat stress indices
 284 in simple regression analysis are extremely similar to those for temperature due to the dominant role
 285 of temperature in these heat stress indices (see Table 4). This is because heat stress indices are all
 286 very sensitive to temperature but less sensitive to RH, as shown in Fig. A1.

287 We further conduct a step-wise regression analysis in order to produce an index that has a
 288 similar form as sWBGT but yields the best correlation with crime rates. While the resulting index
 289 does have slightly different coefficients or weights for T and RH compared to sWBGT, the R^2 values
 290 no longer increase for the six crime types considered here. Based on this, we conclude that the
 291 combined impacts of temperature and relative humidity on Rape and MVR rates can be reasonably
 292 captured by traditional heat stress indices.

293 **Table 4 Simple regression analysis results (R^2) between crime rates and different heat stress indices.**

	Homicide	Assault	Rape	Robbery	Burglary	MVR
sWBGT	0.10*	0.14*	<u>0.46*</u>	0.10*	0.08*	<u>0.52*</u>
HUMIDEX	0.10*	0.13*	<u>0.46*</u>	0.10*	0.08*	<u>0.52*</u>
THIC	0.10*	0.13*	<u>0.45*</u>	0.10*	0.09*	<u>0.51*</u>
THIP	0.10*	0.13*	<u>0.45*</u>	0.10*	0.09*	<u>0.51*</u>
DI	0.10*	0.13*	<u>0.45*</u>	0.10*	0.09*	<u>0.51*</u>

294 * denotes a significance level lower than 0.05

295 To examine the combined impacts of socio-economic factors and heat stress on Rape and MVR,
 296 two methods are used. First, the impact of socio-economic factors on Rape and MVR is assumed to
 297 be time invariant. Second, the impact of socio-economic factors on Rape and MVR is assumed to be
 298 a linear function of GDP. That is, in the following equation,

$$299 \text{ Crime_Rate} = \lambda \text{GDP} + \alpha_1 \text{sWBGT} + \varepsilon \quad (5)$$

300 λ is zero in the first method and is non-zero in the second method. Due to the significant differences
 301 in the magnitude of these variables (GDP, sWBGT and crime rates), data are first normalized
 302 following

$$303 X = \frac{x - \text{MinValue}}{\text{MaxValue} - \text{MinValue}} \quad (6)$$

304 **Table 5 The values of α_1 , λ , and R^2 in two different methods**

Crimes	Rape	Rape (with GDP)	MVR	MVR (with GDP)
α_1	0.462	0.461	0.577	0.583
λ	-	0.041 (not significant)	-	-0.315
R^2	0.45	0.45	0.52	0.72

305 The results show that whether including GDP in Eq. 5 does not matter much for Rape as the R^2
306 value is the same (0.45) and $\lambda = 0.04$ in the second method is not significant. On the other hand, after
307 considering the impact of GDP on MVR, the R^2 value becomes 0.72, which is much larger than that
308 with only sWBGT ($R^2 = 0.52$), indicating that MVR is indeed significantly correlated with GDP.
309 Interestingly, it is shown that λ for MVR is -0.315 in the second method, implying that GDP is
310 negatively correlated to MVR rate. This result indicates that although higher GDP may be
311 accompanied by increases in the exposure of valuable targets and the number of offenders, higher
312 GDP is also often associated with a larger population (hence the rate is reduced) and tends to lead to
313 increased security level in China.

314 **3.3 Future changes in crime rates**

315 Based on the relation between crime rates and sWBGT (see [Table 5](#)), monthly outputs from 13
316 CMIP5 models (see [Table 2](#)) are used to estimate future changes in crime rates due to changes in
317 climate variables in Tangshan towards the end of the 21st century (2094–2099). Changes in GDP are
318 not considered here given our focus on the role of climate. As such, we also use the α_1 values
319 obtained by the first method (see [Table 5](#)) in Eq. 3 for projection. Note that the two methods yield
320 almost identical α_1 values. Three representative concentration pathways (RCP) are analyzed: RCP2.6,
321 RCP4.5 and RCP8.5. We first examine whether the projected changes in the climatic variables are
322 within the envelope of conditions found today or represent an extrapolation outside the range of
323 current conditions (not shown). As expected, although some model results are outside the range of
324 observations, the ensemble mean is well within the observed range in the current climate.

325 As shown in [Table 6](#), Rape and MVR experience increases towards the end of 21st century but
326 the increases are highly dependent on the RCPs. The changes are relatively small (lower than 5%)
327 under RCP2.6 and RCP4.5. However, relatively strong increases (about 10%) are observed for Rape

328 under RCP8.5 scenarios. The uncertainties in the projection reflect the model spread.

329 **Table 6 Percentage changes in crime rates towards the end of the 21st century (2094 – 2099).**

Crimes	Rape	MVR
RCP2.6	0.9% (3.2%)	0.2% (1.1%)
RCP4.5	3.5% (2.1%)	0.9% (0.8%)
RCP8.5	9.5% (5.3%)	2.6% (2.1%)

330 *Numbers out of parentheses indicate the mean of 13 global climate model results and numbers in parentheses
331 represent uncertainties due to the spread of climate simulations.

332 **4 Conclusions and discussions**

333 This study demonstrates a strong influence of climate variables including temperature and
334 relative humidity on crime rates using crime statistics and observed climate records collected in
335 Tangshan, China. It is found that temperature is not the only climatic variable that has significant
336 correlations with crime rates; relative humidity is also associated with certain crime types.
337 Seasonality plays an important role, which can be reasonably explained by the Routine Activity
338 theory. Traditional heat stress indices reasonably capture the combined impact of these climate
339 variables on crime rates. Using global climate model simulations, one violent crime (Rape) is
340 estimated to increase by $3.5 \pm 2.1\%$ under the RCP4.5 scenario and by $9.5 \pm 5.3\%$ under the RCP8.5
341 scenario; while one property crime (MVR) is estimated to increase by $2.6 \pm 2.1\%$ under RCP8.5 at
342 the end of the 21st century due to climate change.

343 There are a few important implications that need to be pointed out. First and foremost, the
344 influence of socio-economic factors on crime rates is complicated. Here we assume that the
345 influence of socio-economic factors is a linear function of GDP. Using simple regression, we find
346 that GDP significantly correlates with MVR rates and including GDP does make a difference in the
347 regression results. When GDP is considered, the R^2 value increases from 0.52 to 0.72. The influence
348 of GDP on Rape rate is relatively small, and when we include GDP, the results do not change much.
349 Second, we do not differentiate “climate variability” from “climate change” as both are included in

350 monthly variations of climate variables in observational data and climate model results. It is clear
351 from Fig. 1 that the seasonal cycle is a significant factor that induces good correlations between
352 certain crime rates and climatic variables. As a result, future changes in Rape and MVR can be
353 induced by changes in the seasonal cycle and/or the long-term change in the mean climate state.
354 Third, although the focus of our study is on climate variability and change, we acknowledge that
355 fluctuations in temperature, relative humidity, and wind speed at daily scales (i.e., weather variability)
356 are probably more related to fluctuations in crime rates if heat stress were to play an important role.
357 This may be also why the R^2 values in our study are only in the medium level (around 0.2 to 0.5).
358 However, we stress that our analyses of observational data and model simulations are performed at
359 the same time scale (i.e., monthly), and hence the estimations are consistent with the assumptions
360 and the scale selected in our study. Finally, it is important to point out that our study is focused on
361 only one city in China. Consequently, although our results are expected to have policy implications
362 for the city of Tangshan and potentially the greater Hua-bei area of China, whether these results are
363 broadly transferable is a question that needs to be explored in future investigations.

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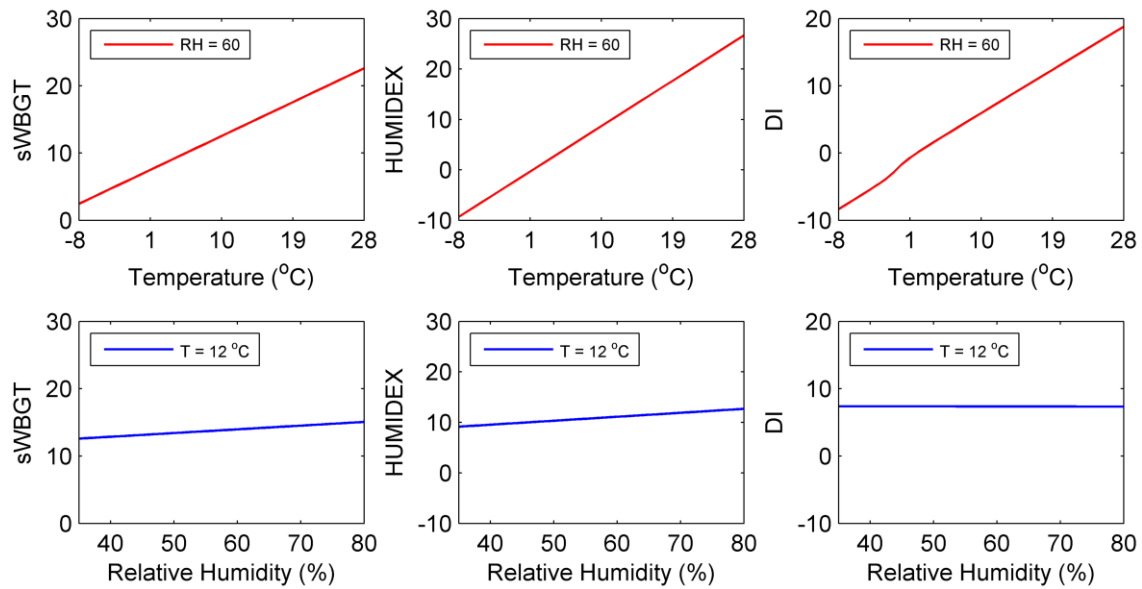
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483

484 **Appendix**

485 **Sensitivity analysis of heat stress indices to changes in temperature and relative humidity**



486

487 **Fig. A1 Sensitivity analysis of heat stress three indices: sWBGT, HUMIDEX and DI.**

488 It can be seen that sWBGT is very sensitive to temperature but less sensitive to RH, which is
 489 why the R^2 values for sWBGT are quite similar to those for temperature. Other indices analyzed here
 490 including HUMIDEX and DI are also very sensitive to temperature but less sensitive to RH.

491

492 **Explanation of crime data used in this study**

493 The crime data in China are collected in different ways. The 110 calls data (like 911 calls data
 494 in the US) provide one way of estimating the crime incidents. However, this is a voluntary reporting
 495 system and the crime types cannot always be confirmed at the moment when people dial 110 for help.
 496 Another source of crime data is from the crime statistics database in which the crime type is
 497 confirmed. The data used in this paper is from the crime statistics database provided by the
 498 Municipal Public Safety Bureau of Tangshan City. All data used in this paper are raw data without
 499 any modification. An example of the data format is shown as [Table A1](#). The data used in this study is
 500 from the middle column named “Cases confirmed”.

501

502 **Table A1 An example of the crime data record in Tangshan, China**

Crimes	Cases reported	March 2014	
		Cases confirmed	Cases solved
...
Homicide	8	8	7
Assault	60	56	45
Rape	23	23	16
Robbery	41	40	10
Burglary	1499	1389	382
MVR	28	27	1
...
In total	-	--	=

503