Regional Ambient Temperature Is Associated with Human Personality

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Human personality traits differ across geographic regions[1-5]**. However, it remains unclear what generates these geographic personality differences. Since humans constantly experience and react to ambient temperature, we propose that temperature is a critical environmental factor that is associated with individuals' habitual behavioral patterns and thus with fundamental dimensions of personality. To test the relationship between ambient temperature and personality, we conducted two large-scale studies within two geographically large yet culturally distinct countries: China and the United States. Using data from 59 Chinese cities (N = 5,587), multilevel analyses and machine learning revealed that individuals who grew up in areas with milder temperatures (i.e., closer to 22 °C) scored higher on personality factors related to socialization/stability (agreeableness, conscientiousness, emotional stability) and personal growth/plasticity (extraversion, openness to experience). These relationships between temperature clemency and personality factors were replicated in a larger dataset of 12,499 ZIP-code level locations (the lowest geographic level feasible) within the United States (N = 1,660,638). Taken together, our findings provide a perspective on how and why personalities vary across geographic regions beyond past theories (subsistence theory, selective migration theory, pathogen prevalence theory). As climate change continues across the globe, we may also observe concomitant changes in human personality.**

A wealth of evidence suggests that personality traits differ across geographic regions[1-5]. Such geographic variation in personality has been shown to predict a broad array of psychological, political, social, economic, and health outcomes[3,4,6]. One critical question that remains, however, is what generates these geographic differences in personality.

Humans constantly experience and react to ambient temperature. Since temperature varies markedly across the globe, it is conceivable that temperature shapes the fundamental dimensions of personality by affecting the habitual behaviors that constitute personality traits. Temperature could mold personality directly by

influencing individual behaviors (e.g., exploring outdoors versus staying indoors), and less directly by influencing collective activities (e.g., agriculture) that guide individual behaviors[7]. Consequently, regions with different ambient temperatures may result in different constellations of personality traits.

Personality is defined as "the interactive aggregate of personal characteristics that influence an individual's response to the environment"[8]. The hundreds of personality traits used to describe humans are largely captured by five broad dimensions, often called the Big Five: agreeableness, conscientiousness, emotional stability, extraversion, and openness to experience[9]. These five personality factors can be further aggregated into two higher-order factors: "Alpha" (agreeableness, conscientiousness, emotional stability), which represents a socialization and stability factor, and "Beta" (extraversion and openness to experience), which represents a personal growth and plasticity factor[10,11].

We propose that ambient temperature clemency is a key factor that relates to personality. This proposition is rooted in the fact that, as a warm-blooded species, humans have the existential need for thermal comfort[12-15]. Clement (i.e., mild) temperatures encourage individuals to explore the outside environment, where both social interactions and new experiences abound; in contrast, when ambient temperature is either too hot or too cold, individuals are less likely to go outside (e.g., to meet up with friends, to try new activities)[16]. This perspective is consistent with attachment theories, which state that individuals are more likely to explore their environments when they feel psychologically secure[17,18].

Based on this reasoning, we hypothesize that individuals who grow up in more clement temperatures will be higher on both the socialization factor (Alpha) and the personal growth factor (Beta). Regarding the socialization factor Alpha, research has found that personality traits develop partly through social interactions[19,20]. More clement temperatures facilitate social contact[16], for which agreeableness, conscientiousness, and emotional stability are important lubricants[21]. Moreover, clement temperatures have been shown to enhance positive mood[22] and lead

individuals to behave more prosocially[23]. Regarding the personal growth factor Beta, more clement temperatures promote a wider range of activities, which may lead individuals to become more extraverted and open to new experiences[24]. A study of 49 cultures revealed that the mean temperature of a country was positively related to people's perception of how extraverted and open a typical person in that culture was; however, this study did not examine how temperature was related to actual personalities beyond these stereotypical perceptions[25]. In another seminal study of 1,662 Chinese residents[13], Van de Vliert and colleagues found that individuals from provinces with more clement temperatures scored higher on individualism—a cultural value dimension positively correlated with extraversion[26].

Our temperature clemency perspective adds to several key theories that speak to geographic variation in personality[3,12,26,27]. First, subsistence theory posits that different subsistence strategies can produce geographic differences in personality-related cultural constructs[7,28]; for example, members of farming and fishing communities, which value harmonious social interdependence, display greater holistic tendencies than members of herding communities, which value individual decision-making and social independence[28]. Second, the selective migration theory of personality proposes that selective migration patterns can produce geographic differences in personality. According to this view, people selectively migrate to regions that fulfill and reinforce their physical and psychological needs[3]. Third, the pathogen prevalence theory of personality suggests that, as a self-protective mechanism, individuals exhibit lower extraversion and openness to experiences in regions that are higher on disease-causing pathogens[29].

There is ample evidence that ambient temperature affects agricultural activities (when and what to farm)[28], individuals' migration decisions[3], and pathogen prevalence[30]. Therefore, ambient temperature likely has significant explanatory power for geographic variation in personality. Overall, our temperature clemency perspective of personality offers a mechanism for why and how macro-level environmental forces might shape individual-level personality.

Several methodological problems have plagued the few investigations into geographic differences in personality. Most notably, previous research has largely focused on personality differences across *broad* geographic regions (e.g., across countries)[1-5], which makes it difficult to eliminate the confounding effects of other variables, such as between-country cultural differences. To rule out such cultural differences and isolate the effects of ambient temperature, it is preferable to use subject samples from within a single country. Of course, that single country must be of substantial geographic size to capture sufficient variance in temperature. A related issue with examining personality at the country level is that analyses at such a broad level may obscure meaningful *within*-country regional variances in temperature and personality. Thus, it is important to analyze the effects of temperature on personality at the lowest geographic levels feasible—city level or even ZIP-code level—within which variances in both temperature and personality differences will be minimal.

To overcome these methodological concerns, we conducted two separate, large-scale studies within two geographically large yet culturally distinct countries: China and the United States. Given that the period from birth to adulthood is particularly critical for personality development[31], for each participant we collected meteorological data of the geographic location where he or she grew up.

In Study 1, a total of 5,587 university students (42.4% females, $M_{age} = 22.07$, $SD_{age} = 2.05$) born and raised in 59 Chinese cities completed a personality survey online in return for individualized feedback (see Supplementary Information for details). These cities covered all provincial-level administrative divisions in continental China (see Figure 1 and Supplementary Table 1). To preclude reverse causality, where certain personalities may cause individuals to migrate to cities with certain temperatures, we limited our sample to students who had spent their pre-college youth in their birthplace. To rule out another alternative explanation—that parents with certain personalities chose to migrate to a certain city and then gave birth to children who resemble their personalities—we further limited the sample to participants whose birthplace matched their ancestral home (i.e., *jiguan*, the home of their patrilineal ancestors). Importantly, all results remained substantively unchanged without these exclusion criteria.

In line with past research[13,14], we computed a "temperature clemency" variable, –|mean temperature – 22°C|, which measures the extent to which a city's ambient temperature *is close to* the psychophysiological comfort optimum of 22°C (about 72°F). In other words, the further a city's temperature is from 22°C, the less clement it is.

At the city level, temperature clemency was positively correlated with both the Alpha and Beta factors (both p's < .006), as well as with each of the Big-Five personality factors (all p's < .05, except that agreeableness, p = .160; see Supplementary Table 5). As an illustration, Figure 1a and 1b map the temperature clemency of each city with Alpha and Beta, respectively. In contrast, air pressure or wind speed was not significantly correlated with Alpha, Beta, or any of the Big Five (all p's > .23).

Since the 5,587 participants (level 1) were nested within the 59 cities (level 2), we conducted multilevel analyses to account for the statistical dependence within each city and the fact that different cities had different sample sizes (see Supplementary Tables 6-12). Consistent with the city-level correlational results, temperature clemency was positively associated with Alpha, Beta, and each of the Big Five even after accounting for individual-level control variables age, gender, and acquiescent response style (all p's < .01) and city-level control variables population density, GDP per capita, average annual rice-farming area, average annual wheat-farming area, influenza incidence, and the standard deviation of the mean temperature (all p's < .05).

As a robustness check, we also computed another version of temperature clemency using –(|minimum temperature – 22°C| + |maximum temperature – 22°C|)[13,14]. All results remained substantively unchanged when we used this measure as the predictor in multilevel analyses (all p's < .01) (see Supplementary Table 13). Figure 2a compares the effect sizes (calculated by *t*-to-*r* transformation) of all the predictor variables and highlights the importance of temperature clemency in the Chinese sample.

In addition to multilevel analyses, we conducted machine learning analyses to explore which of the variables were likely important predictors of personality (see Supplementary Figures 8-12). Consistent with the results of multilevel modeling, conditional random forest analyses reliably identified temperature clemency to be an

important predictor of each of the seven personality factors. For analytical details, see Supplementary Information.

In support of our temperature clemency perspective of personality, Study 1 demonstrated a clear relationship between ambient temperature clemency and personality among Chinese participants: individuals who grew up in cities with milder temperatures scored higher on both the socialization factor (Alpha) and the personal growth factor (Beta) of personality, as well as on each of the Big Five personality factors.

Study 2 sought to extend Study 1 in several important ways. First, we investigated whether the effects of temperature clemency on personality factors would replicate within the United States—another geographically large yet culturally distinct country. Second, we more closely scrutinized these effects by collecting temperature data at the lowest geographic level feasible: the ZIP-code level. Third, to examine the robustness of these effects, we employed another well-validated measure of the Big-Five personality factors (see Supplementary Information). Fourth, we used an even larger participant sample ($N > 1.6$ million) that was representative of the general U.S. population in terms of age, social class, and education levels (age range = 16~60, as opposed to only university students).

Study 2 involved 1,660,638 Americans who participated in return for a customized personality evaluation (65.3% female; $M_{age} = 27.05$ years, $SD_{age} = 11.00$; 17.0% with a college degree, 9.44% with a graduate degree) (for details, see Supplementary Information). Participants reported the U.S. ZIP code where they spent most of their youth (12,499 U.S. ZIP codes in 8,102 cities). As in Study 1, we operationalized ambient temperature as being "more clement" to the extent that it is closer to 22°C.

Replicating the Chinese data, multilevel analyses (see Supplementary Tables 17-23) revealed that temperature clemency was positively associated with Alpha, Beta, and each of the Big Five after accounting for individual-level control variables age, gender, education, and acquiescent response style (all p's < .015) and ZIP-code level control variables humidity, wind speed, population density, GDP per capita, the percentages of civilians employed in the primary sector (e.g., agriculture), in the secondary sector (e.g., construction, manufacturing), and in the tertiary sector (i.e., service) (all p's < .005). Importantly, temperature clemency was the only

meteorological variable that was consistently and positively associated with each of the seven personality factors; for example, neither humidity nor wind speed was significantly associated with emotional stability (both p's > .25).

Figure 2b compares the effect sizes (calculated by t-to-r transformation) of all the predictor variables and highlights the importance of temperature clemency in the U.S. sample.

Consistent with the results of multilevel modeling, machine learning analyses using conditional random forest again reliably identified temperature clemency to be an important predictor of each of the seven personality factors (see Supplementary Figures 13-17).

In sum, two large-scale studies from China and the United States found that the ambient temperature during one's youth related to the key dimensions of personality: individuals who grew up in more clement regions scored higher on both the socialization factor (Alpha) and the personal growth factor (Beta) of personality, as well as on each of the Big Five personality factors. These effects were robust when controlling for various factors that might affect personality-related constructs: selective migration, individual response style, demographic factors (age, gender, education), socioeconomic factors (population density, GDP per capita, rice-farming area, wheat-farming area), ecological factors (pathogen prevalence), and other meteorological factors (air pressure, humidity and wind speed). It is particularly telling that our large datasets provided converging evidence from two geographically large yet culturally distinct countries. Taken together, these findings are consistent with our temperature clemency perspective of personality: growing up in temperatures that are close to the psychophysiological comfort optimum encourages individuals to explore the outside environment, thereby influencing their personalities.

The present research adds to past theories and findings on how socioecological factors (subsistence strategies, selective migration, and pathogen prevalence) are associated with human personality. Theoretically, they point to a likely antecedent of these factors: ambient temperature. Empirically, we explicitly controlled for selective migration, subsistence strategies, and pathogen prevalence in the Chinese sample. Moreover, whereas past studies focused on broad geographic levels (e.g., countries),

we examined the effects of ambient temperature on personality at the lowest geographic levels feasible (city and ZIP-code levels).

While our temperature clemency perspective on personality offers a mechanism for why and how macro-level environmental forces might influence individual-level personality, we note that temperature clemency is one of many factors associated with human personality. In addition, standardized partial effect size plots (Figure 2) and variable importance plots (Figure 3 and Supplementary Figures 8-17) suggest that temperature clemency might be more associated with the personalities of Chinese individuals than those of American individuals. Future research could further examine such cross-cultural differences.

In light of the present findings, it is also important to highlight IJzerman and colleagues' social thermoregulation theory[18,32], which posits that people seek "social warmth" in cold environment because an important function of social relationships is to facilitate the regulation of body temperature. For example, a recent study found that compared to residents of warmer climates, residents of colder climates reported a wider variety of social ties[33]. Critically, social thermoregulation theory and our temperature clemency perspective of personality are not necessarily at odds with each other: while social thermoregulation theory suggests that cold climate *compels* people to seek social warmth, our findings suggest that clement climate *encourages* people to explore the outside environment to engage in more social activities and new experiences that are conducive to socialization (i.e., Alpha) and growth (i.e., Beta).

While much is known about the effects of temperature on human health and performance, the present research examined its relationship with personality. Our findings offer insights into why people in different parts of the world exhibit different personality traits and behaviors. As climate change continues across the globe, we may also observe concomitant changes in human personality. Of course, questions about the size and extent of these changes await future investigation.

Methods

For analytical details of multilevel and machine learning analyses, see Supporting Information.

Study 1. This research project was approved by the Institutional Review Board of Peking University. All participants completed the 40-item Mini-Markers Scale that assessed the Big-Five personality factors, each of which consisted of eight items ($\omega_{t\text{[agreeableness]}} = .79$, $\omega_{t\text{[conscientiousness]}} = .88$, $\omega_{t\text{[emotional stability]}} = .85$, $\omega_{t\text{[extraversion]}} = .83$, $\omega_{t\text{[openness to experience]}} = .88$) (see Supplementary Information). Based on the personality literature[10,11], we then further aggregated the Big Five to the higher-level factors of Alpha (agreeableness, conscientiousness, emotional stability) and Beta (extraversion, openness to experience), both of which demonstrated high levels of internal consistency ($\omega_{t\text{[Alpha]}} = .89$, $\omega_{t\text{[Beta]}} = .90$).

For each of the 59 cities, the China Meteorological Administration provided us with city-level data of five meteorological indices across the latest available 40 years (1971-2010): average annual mean ambient temperature (2.2~23.3°C), average annual minimum ambient temperature (-3.0~20.8°C), average annual maximum ambient temperature (7.8~27.8°C), average annual air pressure, average annual wind speed. In line with past research[13,14,34,35], we computed a "temperature clemency" variable, – |mean temperature – 22°C|, which measures the extent to which a city's ambient temperature *is close to* the psychophysiological comfort optimum of 22°C (about 72°F). In other words, the further a city's temperature is from 22°C, the less clement it is.

In light of prior research on geographic differences in personality (e.g., subsistence theory, pathogen prevalence theory), we also collected pertinent city-level control variables for at least ten years that overlapped with participants' childhood: GDP per capita, population density, average annual rice-farming area, average annual wheat-farming area, and influenza incidence (see Supplementary Information). To reduce the effect of idiosyncrasies of any particular year, we computed the mean value across those years for each of these control variables. Moreover, we computed an "acquiescent response style" score for each participant based on his/her responses to the personality items of the Mini-Markers Scale; this variable controlled for individual differences in response style, where individuals from regions with more clement temperatures might "consistently agree (yea-saying) or consistently disagree (nay-saying) with questionnaire items, regardless of their content"[36,37]. Finally, because

variation in temperature might also affect personality (over and above mean temperature), we also controlled for the standard deviation of mean temperature for each city.

Study 2. This research project was approved by the Institutional Review Board of the University of Texas. Each participant completed the 44-item Big Five Inventory ($\omega_{t[\text{agreeableness}]} = .84$, $\omega_{t[\text{conscientiousness}]} = .86$, $\omega_{t[\text{emotional stability}]} = .88$, $\omega_{t[\text{extraversion}]} = .91$, $\omega_{t[\text{openness to experience}]} = .84$) (see Supplementary Information). As with the Chinese data, we aggregated the Big Five into the higher-level Alpha and Beta, both of which demonstrated high levels of internal consistency ($\omega_{t[\text{Alpha}]} = .90$, $\omega_{t[\text{Beta}]} = .86$).

In addition, participants reported the U.S. ZIP code where they spent most of their youth (12,499 U.S. ZIP codes in 8,102 cities). For each ZIP code, we collected the following meteorological variables: average annual mean ambient temperature, average annual humidity, and average annual wind speed (see Supplementary Information). As in Study 1, we operationalized ambient temperature as being "more clement" to the extent that it is closer to 22°C. To control for pertinent economic variables, we also collected ZIP-code level data on GDP per capita, population density, the percentages of civilians employed in the primary sector (e.g., agriculture), in the secondary sector (e.g., construction, manufacturing), and in the tertiary sector (i.e., service). As in Study 1, we again computed an "acquiescent response style" variable to control for individual differences in response style.

Code availability. Analyses were conducted in R and Stata. All code is available upon request.

Data availability. Personality data are available from the corresponding author upon request.

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Author contributions
L.W. conceived the core research idea. W.W., J.G.L., A.D.G. and L.W. designed research; W.W., J.G.L., H.W., S.D.G., P.J.R, W.Y., Q.Z., Y.G., M.Z., W.G., X.Y.G., J.P., J.W., B.L., X.L., Y.M.H., M.L., X.Q.G., Y.C., W.L., K.Y., Q.B., Z.S., Y.H., and L.W. performed research; W.W., J.G.L., H.W., W.Y. and L.W. analyzed data; W.W., J.G.L., A.D.G., S.D.G., P.J.R and L.W. wrote the paper. The first two authors share first authorship.

Competing interests
The authors declare no competing interests.

Figure 1 | Temperature clemency and personality scores of the 59 Chinese cities.
The location of each city is indicated by a vertical bar. The color of each bar
represents temperature clemency (with lighter colors representing more clement
temperatures) and the height represents the corresponding personality score. **a**,
Distribution of temperature clemency and Alpha scores. **b**, Distribution of
temperature clemency and Beta scores.

**Figure 2 | Standardized partial effect sizes of the predictor variables in the full
multilevel models (calculated by *t*-to-*r* transformation). a**, Study 1 (the Chinese
sample). **b**, Study 2 (the U.S. sample).

**Figure 3 | Variable importance plots of the predictor variables in machine
learning analyses. a**, Alpha (Study 1). **b**, Beta (Study 1). **c**, Alpha (Study 2). **d**, Beta
(Study 2).