Preplanned Studies

An Early Warning System for Heatwave-Induced Health Risks in China: A Sub-Seasonal to Seasonal Perspective — China, 2022

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Summary

What is already known about this topic?

Climate change has had a detrimental impact on global health, particularly through the rise of extreme heatwaves. Presently, the early warning system for heatwave-related health risks can forecast potential dangers several days in advance; however, long-term warnings fall short.

What is added by this report?

This report introduces a novel early warning system aimed at predicting heatwave-induced health risks in China at sub-seasonal to seasonal timescales. The outcomes of the assessment suggest this system holds significant potential.

What are the implications for public health practices?

The system facilitates advanced assessment of both the scale and dispersal of risk among various demographic groups. This allows for the proactive management of potential risks with extended lead times.

Global climate change has had a negative impact on the physical health of populations worldwide, with heatwave events causing significant human mortality and morbidity (*1*). The formation of an early warning system for health risks induced by heatwaves is vital, as it facilitates proactive measures by public health practitioners and public individuals. Current methodologies have developed various systems that provide advance warning several days ahead, effectively lessening heat-related dangers (*2–6*). The adoption of long-term pre-warning measures aids in preparing individuals and policymakers to take informed actions to reduce potential risks.

Despite the initial success of these long-term heatwave predictions, there remains a notable deficit in the provision of a health-risk warning system that covers the sub-seasonal to the seasonal scales (spanning two weeks to two months). The aim of this paper is to present a system that successfully addresses this gap.

By incorporating the China heatwave-attributable mortality model (*7–8*) with real-time temperature forecasts from the China Meteorological Administration-Climate Prediction System (CMA-CPSv3), this system provides up-to-date estimates of mortality rates and burdens for the forthcoming two months. As such, this system is poised to serve as a valuable tool for public health practitioners, enabling them to better plan personnel deployments and effectively allocate resources.

This study aims to combine heatwave events and health-risk assessment tools by using real-time, rolling temperature data projected for the subsequent 60 days from the advanced CMA-CPSv3 prediction system. Notably, the CMA-CPSv3 applies the enhanced resolution version of the Beijing Climate Center Climate System Model (BCC-CSM2-HR), recognized for its accuracy in predicting high temperatures within China (*9*). Initially, we commenced by systematically rectifying the temperature components produced by the CMA-CPSv3. A series of at least 3 days during the summer months (May to September) when the daily peak temperature surpasses the 92.5th percentile of the reference period (1961–2020) is characterized as a heatwave.

We utilized the nationwide heatwave-attributable mortality model established by Chen et al. (*7–8*) to analyze the health risks associated with heatwaves, including related mortality burden and death rate. This model investigates the specific exposure-response functional relationships between heatwaves and ensuing deaths across different climate zones using generalized linear models and meta-analysis. Estimations of mortality burden ascribed to heatwaves employ risk appraisals applicable to respective gridded heatwave series and nationwide mortality. The model considers factors such as population size, mortality rate, heatwave frequency, and exposure-response dynamics. By integrating the computed heatwave day data into the model, we ascertained the death burden and death rate due to heatwave-induced fatalities (depicted as gridded mortality burden per million population). A representation of this approach is illustrated in Figure 1.

Table 1, issued on July 1, 2022, provides estimates for the number of heatwave days expected in China over the subsequent two months. Data indicate a higher projection of heatwave days for July in regions like Western Sichuan, Chongqing, and other areas of Central China, with more than 20 heatwave days predicted per month. Similarly, nearly 20 days of heatwave occurrences were estimated for Northwest China, inclusive of areas such as Ningxia and Xinjiang. Moving into August, the northern reaches of Northeast

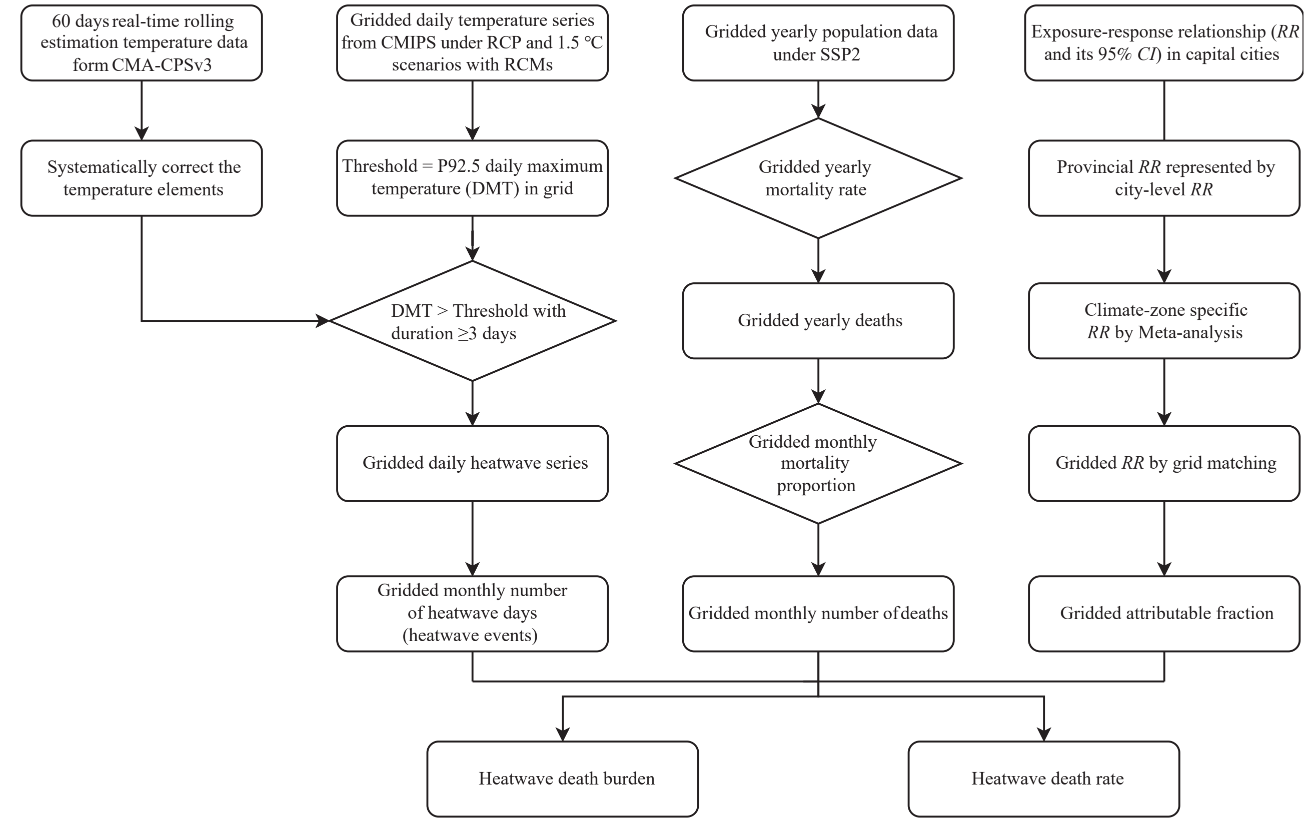

FIGURE 1. Flow diagram illustrating the operational process of the early warning system.
Abbreviation: RCMs=regional climate models; RCP=representative concentration pathways; SSP=shared socio-economic pathway; CMIP=coupled model intercomparison project; *RR*=relative risk; AF=attributable fraction; DMT=daily maximum temperature.

TABLE 1. Top 10 provincial-level administrative divisions (PLADs) by number of heatwave days, resulting death burden, and death rate.

Heatwave days				Heatwave-induced death burden				Heatwave-induced death rate			
0–30 days		31–60 days		0–30 days		31–60 days		0–30 days		31–60 days	
PLAD	Value	PLAD	Value	PLAD	Value	PLAD	Value	PLAD	Value	PLAD	Value
Chongqing	20.63	Anhui	20.01	Henan	3,530	Henan	3,402	Xinjiang	17,318	Xinjiang	21,003
Ningxia	19.25	Xinjiang	19.72	Shaanxi	1,817	Sichuan	1,750	Inner Mongolia	9,119	Inner Mongolia	12,471
Shaanxi	19.10	Chongqing	16.26	Sichuan	1,809	Anhui	1,666	Gansu	6,498	Gansu	4,418
Gansu	18.48	Hebei	15.61	Hubei	1,498	Hubei	1,663	Qinghai	4,588	Heilongjiang	4,060
Qinghai	18.44	Henan	14.79	Shandong	1,050	Jiangsu	1,331	Shaanxi	3,682	Henan	2,412
Hebei	18.00	Guizhou	14.76	Gansu	959	Shandong	1,316	Xizang	3,199	Qinghai	2,335
Xinjiang	17.00	Hunan	12.94	Anhui	941	Shaanxi	893	Sichuan	2,851	Sichuan	2,113
Sichuan	15.63	Inner Mongolia	12.85	Shanxi	736	Xinjiang	804	Henan	2,571	Hubei	1,837
Henan	15.45	Jiangsu	12.30	Xinjiang	608	Inner Mongolia	642	Heilongjiang	2,268	Shaanxi	1,751
Anhui	12.14	Gansu	12.09	Inner Mongolia	525	Heilongjiang	603	Hubei	2,085	Anhui	1,452

China forecast an increased frequency of heatwave days, with most regions predicted to experience over 20 such days per month on average. Of particular note is the Yangtze River Basin, which endured the most intense heatwave event ever recorded in the late summer of 2022 (*10*). As outlined in Table 1, this model accurately predicted this distinct pattern a month in advance.

The projected results were released on July 1, supplemented by real-time daily forecasts for one-month duration heatwave days in the summer of 2022. Figure 2 compares estimated and actual data, with solid lines reflecting observed data and dashed lines illustrating CMA-CPSv3 predictions. The figure demonstrates CMA-CPSv3's effective prediction of heatwave events during the summer of 2022. Accurate forecasting of heatwave days forms the basis for dependable subsequent estimations of heatwave health risks.

The study provided an analysis of the mortality rate due to heatwaves in July and August 2022, as depicted in Table 1. When contrasted with heatwave occurrences, the distribution of heatwave-related mortality correlates strongly with heatwave patterns in central China. Henan and Sichuan, both populous provinces, recorded the highest mortality rates due to heatwaves, with approximately 3,400 and 2,000 deaths respectively. Upon conducting a subgroup analysis, cardiovascular diseases (CVD) emerged as the leading cause of heatwave-induced mortality, contributing to an estimated 80% of the cases. Further, seniors and females were found to be at a relatively higher risk, accounting for around 75% and 70% of cases respectively.

The mortality burden indicator can enable policymakers and public health practitioners to allocate resources effectively. Nonetheless, it is crucial to acknowledge that the impact of the mortality burden during heatwaves is related to the local population size, which may limit its relevance on an individual basis. Therefore, this indicator also includes a heatwave-related mortality rate, derived from the mortality burden per million people during heatwaves. Over a span of two months, the highest risk was observed in Xinjiang, with an estimated heatwave-related mortality risk of about 20,000 per million individuals monthly. This was closely followed by Inner Mongolia, which had a risk estimated at 10,000 individuals per million monthly. Notably, the risk in August surpassed that of July.

DISCUSSION

This study presents two results within the sub-seasonal to a seasonal early warning system for heatwave-related health risks: death burden and death rate. These results can be beneficial for a variety of users. For policymakers and public healthcare practitioners, the distribution of heatwave incidents and a ranking system for province-wide mortality burden due to heatwaves can help inform the scope of heatwave impacts, prioritize critical areas, and effectively allocate resources. For individual users, the mortality rate due to heatwaves gives a more precise understanding of an individual's risk during a heatwave event, assisting in making well-informed travel plans and activity scheduling.

The two outputs show variations in detail when compared with the prediction of heatwave days. For instance, while the northeastern and northwestern regions of China experience more heatwave days, they

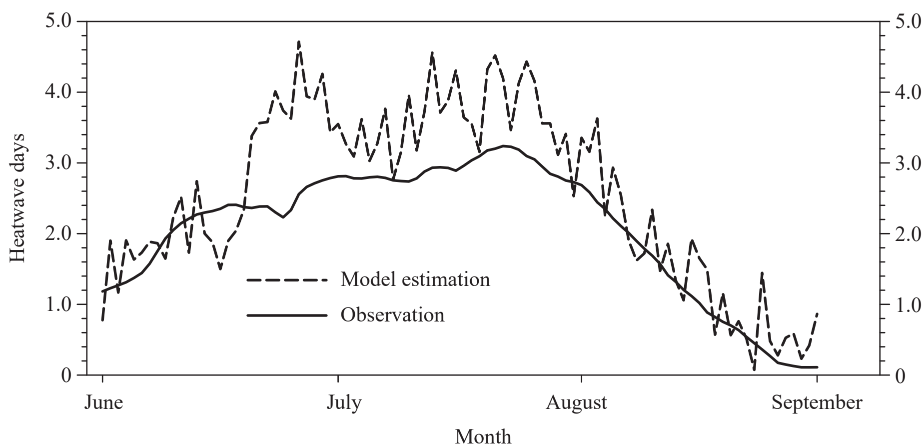

FIGURE 2. Comparison of the average heatwave days predicted over the next 30 days in China (dashed curve) with actual observations (solid curve).

show a lower heatwave-induced mortality burden due to their lower population densities. The heatwave-induced mortality rate provides a more accurate representation of the effect of heatwave duration on individuals. As expected, higher heatwave mortality rates align with the predicted heatwave days in the northeastern and northwestern regions. However, despite the high number of heatwave days in Sichuan-Chongqing, there is no significant increase in heatwave-induced mortality rate. This is likely due to the region's higher adaptive capacity to high temperatures, as its population has been exposed to such conditions for a long period of time. Consequently, despite experiencing the same number of heatwave days as in other regions, the risk in Sichuan-Chongqing is lower than in the northeastern and northwestern regions of China.

This study possesses numerous limitations. Predominantly, the CMA-CPSv3 data estimation appeared to slightly exaggerate the quantity of heatwave days in July. Further, the all-encompassing model for heatwave-related mortality utilized in this study does not accommodate prospective shifts in population exposure and vulnerability. Additionally, the hypothesized burden of heatwave deaths lacks substantiation through real-time mortality data. To address these limitations, the following remedies are suggested. 1) The improvement of climate model predictive capabilities is imperative. The enhancements presented with the development of the BCC-CSM2-HR model will allow for greater accuracy in the data derived from CMA-CPSv3. 2) The usage of multi-year estimation results for adjustments is advocated. The CMA-CPSv3 system, applied in this study, underwent certain modifications. Nonetheless, its efficacy is limited during months of extremely high temperatures due to the inadequate representation of such extreme conditions in the correction dataset. However, the performance of the modification is projected to improve as more estimated data from CMA-CPSv3 becomes available. 3) It is crucial to frequently update the nationwide model of mortality attributable to regional heatwaves to accurately depict the changing exposure and vulnerability of the population. 4) The enhancement of cross-disciplinary collaboration is of the utmost importance. This includes promoting a closer cooperation with the China CDC for the exchange of real-time mortality data and the validation of the system's outputs. Such collaboration will significantly contribute to the improvement of the system's performance.

In conclusion, the early warning system for health risks induced by sub-seasonal to seasonal heatwaves offers timely and quantitative assessments of both the impact magnitude and risk levels linked to heatwaves in China. This tool accommodates a broad spectrum of users and delivers crucial insights.

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REFERENCES

1. IPCC. IPCC sixth assessment report—summary for policymakers. IPPC Rome; 2022.
2. Casanueva A, Burgstall A, Kotlarski S, Messeri A, Morabito M, Flouris AD, et al. Overview of existing heat-health warning systems in Europe. Int J Environ Res Public Health 2019;16(15):2657. http://dx.doi.org/10.3390/ijerph16152657.
3. Chen C, Liu J, Zhong Y, Li TT. A review on heat-wave early warning based on population health risk. Chin J Prev Med 2022;56(10):1461 – 6. http://dx.doi.org/10.3760/cma.j.cn112150-20220429-00433-1. (In Chinese).
4. Kotharkar R, Ghosh A. Progress in extreme heat management and warning systems: A systematic review of heat-health action plans (1995-2020). Sustain Cities Soc 2022;76:103487. http://dx.doi.org/10.1016/j.scs.2021.103487.
5. Issa MA, Chebana F, Masselot P, Campagna C, Lavigne É, Gosselin P, et al. A heat-health watch and warning system with extended season and evolving thresholds. BMC Public Health 2021;21(1):1479. http://dx.doi.org/10.1186/s12889-021-10982-8.
6. Matzarakis A, Laschewski G, Muthers S. The heat health warning system in Germany—Application and warnings for 2005 to 2019. Atmosphere 2020;11(2):170. http://dx.doi.org/10.3390/atmos11020170.
7. Chen HQ, Zhao L, Cheng LL, Zhang YL, Wang HB, Gu KY, et al. Projections of heatwave-attributable mortality under climate change and future population scenarios in China. Lancet Reg Health West Pac 2022;28:100582. http://dx.doi.org/10.1016/j.lanwpc.2022.100582.
8. Chen HQ, Zhao L, Dong W, Cheng LL, Cai WJ, Yang J, et al. Spatiotemporal variation of mortality burden attributable to heatwaves in China, 1979–2020. Sci Bull 2022;67(13):1340 – 4. http://dx.doi.org/10.1016/j.scib.2022.05.006.
9. Wu TW, Yu RC, Lu YX, Jie WH, Fang YJ, Zhang J, et al. BCC-CSM2-HR: a high-resolution version of the Beijing Climate Center climate system model. Geosci Model Dev 2021;14(5):2977 – 3006. http://dx.doi.org/10.5194/gmd-14-2977-2021.
10. Zhang DQ, Chen LJ, Yuan Y, Zuo JQ, Ke ZJ. Why was the heat wave in the Yangtze River valley abnormally intensified in late summer 2022? Environ Res Lett 2023;18(3):034014. http://dx.doi.org/10.1088/1748-9326/acba30.