（続紙 1）

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論文題目	Studies on Heat-related Health Risks and Evaluation Methods in Japan: The Effects of Global Warming and COVID-19 Pandemic 日本の熱関連健康リスクとその評価手法に関する研究 －地球温暖化と新型コロナウイルスの影響を踏まえて－		

（論文内容の要旨）

Researchers agree that there is substantial evidence of an increasing trend in both the frequency and duration of extreme temperature events. Several fatal heatwaves have already occurred in the 21st century, causing a large number of deaths in different regions. Increasing extreme temperature events will place more pressure on public health and emergency medical resources in the future, and societies will need to find effective and reliable solutions to adapt to hotter summers. In Japan, there is a great climatic difference between the north and the south. Therefore, high-accuracy heat-related health prediction models that can be applied to most regions are required to assist government institutions and individuals in taking proper countermeasures in advance. To properly formulate adaptation and mitigation strategies, the future trends of heat-related health impacts in Japan under different future scenarios need to be analyzed.

(Finding 1) This study developed an effective method to predict the number of daily heat-related ambulance calls. Both national- and regional-level models were developed to evaluate the performance of machine-learning–based methods for heat-related ambulance call prediction. The national model showed a high prediction accuracy and can be applied to most regions, while the regional model showed extremely high prediction accuracy in each corresponding region and reliable accuracy in special cases (such as the case of Okinawa). I found that the introduction of heatwave features, including accumulated heat stress, heat acclimatization, and optimal temperature, significantly improved prediction accuracy. The adjusted coefficient of determination (adjusted R^2) of the national model improved from 0.9061 to 0.9659 by including these features. My results suggest that disaster management agencies can use this highly accurate model to forecast potential high emergency medical resource burden caused by extreme heat events, allowing them to raise and improve public awareness and prepare countermeasures in advance. The method proposed for Japan in this research can be applied to other countries that have relevant data and weather information systems (Chapter 3).

(Finding 2) This study used bias-corrected global climate models (GCMs) to forecast the total number of summer heat-related ambulance calls under three different Shared Socioeconomic Pathways (SSPs) (SSP-1.26, SSP-2.45, and SSP-5.85) nationally and regionally. In my analysis I have considered the changes in future climate conditions, population and migration in Japan. My analysis demonstrated that at the end of the 21st century, the total number of heat-related ambulance calls in Japan will reach approximately 200,000 per year (nearly three times the current number) under SSP-5.85. Only in SSP-1.26, national heat-related ambulance calls will be well controlled and remain at the current level throughout the century. I also analyzed the difference in heat-related ambulance calls between different regions. Compared to other regions, Kanto (Tokyo metropolitan area) and Kinki (Osaka metropolitan area) are expected to see a larger increase in heat-related ambulance calls because the Japanese population tends to be concentrated in those large metropolitan areas. My results show that strong mitigation strategies are required to avoid the worst scenario SSP-5.85. Although the increase in heat-related ambulance calls under the SSP-2.45 scenario is not as high as under SSP-5.85, the rapid population decline in this scenario will lead to a series of social issues that increase heat-related health risks. The Japanese government needs to find a sustainable development pathway to protect their citizens from the potential heat impacts (Chapter 4).

The COVID-19 pandemic, coupled with more frequent and stronger heatwaves, has introduced a novel confluence of challenges. For example, it has become very difficult for emergency medical transport staff to differentiate between COVID-19 and heat stroke at the scene because they share similar symptoms. Changes in lifestyles caused by COVID-19 and the warming climate have also resulted in a new problem. Actions

that have been applied to prevent COVID-19 led to a higher risk of heat-related health problems. For example, to prevent the spread of COVID-19, individuals were encouraged to stay indoors and ventilate rooms frequently. However, room ventilation in summertime may increase the indoor temperature and therefore increase the risk of a heatstroke. High numbers of heatstroke patients and COVID-19 patients in summertime during the COVID-19 pandemic tend to put an extremely high burden on the emergency ambulance call system. To have a better understanding of the COVID-19 pandemic and to design countermeasures for a future similar pandemic, it is necessary to investigate the effects of the COVID-19 pandemic on heat-related risks and the challenges faced by local fire departments (that operate the emergency medical transport service).

(Finding 3) This study evaluated the impact of the COVID-19 pandemic on heat-related ambulance calls in 2020-2022 and identified the challenges faced by local fire departments in the Kansai region of Japan by using historical data analysis and an online questionnaire survey. This study utilized the heat-related ambulance calls prediction model developed in Chapter 3 based on the historical data (2008 ~ 2019) and projected the expected number of heat-related ambulance calls from 2020 to 2022. Then, a comparison was done between the expected number and the actual number of daily heat-related ambulance calls to examine the changes of heat-related ambulance calls in the six prefectures of the Kansai region. I found a statistically significant decrease, ranging from 77.1% to 96.8%, of heat-related ambulance calls during the COVID-19 pandemic in all Kansai prefectures. The decline in heat-related ambulance calls can be attributed by changes in people's daily lifestyles such as the increase of remote work and decrease of outdoor activities. However, it may also be influenced by the heavy strain on the emergency medical resources. Another finding of this research is about the significant pressures on local fire departments and emergency medical transport systems during the COVID-19 pandemic. The predominant challenge for local fire departments was finding available medical facilities for their patients. Improving the efficiency of emergency medical transport system and enhancing the coordination between the emergency medical services and the healthcare facilities may offer a more resilient response in future crises. However, additional financial support is required from the Japanese government to introduce new technologies in the emergency medical transport systems (Chapter 5).

In this dissertation, I developed a heat-related ambulance call prediction model that can be applied to most regions with high accuracy. As applications of this model, I analyzed the potential heat-related risks Japan may face under future scenarios, as well as the impact of the COVID-19 pandemic on Japan's heat-related ambulance calls. I also suggested some policies and strategies that could help the Japanese government and local institutions to better evaluate future heat-related risks and formulate relevant countermeasures.

However, there are also some limitations of this research. Firstly, the heat-related ambulance call data from the Japanese fire departments used in this study represents only the patients' initial diagnosis information. This data does not reflect subsequent developments in the patients' conditions. Additionally, due to the lack of sufficient data, this study did not consider big events that might significantly increase the heat-related risks, including but not limited to sports events, marathons, natural disasters, etc. The future development of technology and the occurrence of big events are not included in my future scenario analysis. Furthermore, due to many known and unknown factors affecting the usage of the emergency medical transport system, this study lacks sufficient data to analyze the specific impact of each relevant factor on heat-related risks. The effects of heat stress on labor productivity are also omitted from my analysis because of the lack of data.

（続紙 2）

（論文審査の結果の要旨）

本論文では、柯登君は日本の熱関連健康リスクを分析し、その評価手法の確立に貢献している。具体的に、日本のほとんどの地域に応用できる正確度の高い熱関連救急搬送件数予測モデルを開発し、三つの共通社会経済経路（SSP; Shared Socioeconomic Pathways）に基づき、日本における21世紀末までの熱関連救急搬送件数の推計を行っている。また、新型コロナウイルスによる日本の熱関連健康リスクへの影響を定量的、定性的手法の両方を用いて分析している。

本論文の第一の新規性は、複数の地域に応用できる正確度の高い熱関連救急搬送件数予測モデルの開発である（第3章）。複数の地域に応用できる意義として、多様な気候帯が含まれることを指摘できる。先行研究には、特定の地域における正確度の高いモデルや複数の地域における正確度の低いモデルはあるが、柯登君は複数の地域に応用できる正確度の高いモデルを初めて開発できた。

第4章では、柯登君は三つの共通社会経済経路（SSP; Shared Socioeconomic Pathways）に基づき、第3章で開発したモデルを日本における21世紀末までの熱関連救急搬送件数の推計に応用した結果、最悪のシナリオ（SSP 5.85）や中庸シナリオ（SSP 2.45）の場合、日本の熱関連健康リスクは極めて高くなることを明らかにした。また、柯登君は日本全国だけではなく、日本の複数の地域における21世紀末までの熱関連救急搬送件数の推計に成功した。そのような研究成果を挙げた先行研究はない。

本論文の第三の新規性は、新型コロナウイルスによる熱関連救急搬送件数への影響の分析である。新型コロナウイルスの感染拡大が始まった2020年のデータを用いた先行研究はあるが、2020年～2022年のデータを用いた研究は本論文のみである（第5章）。柯登君は新型コロナウイルスの影響により関西における熱関連救急搬送件数が減少していることを明らかにした。新型コロナウイルスの感染拡大の時期に都道府県の消防署が直面した課題を解明するために、柯登君は関西における消防署を対象にアンケート調査を行い、調査の結果、消防署を含む日本政府に対して今後の熱関連健康リスク拡大に対処するための政策提言を行ったことは本論文の実務的な貢献である。

なお、本論文の第3章および第4章の内容は、それぞれ柯登君が筆頭著者として査読付き国際学術ジャーナルに掲載済みである。第5章の内容は、査読付き国際学術ジャーナルに投稿済みであるが、現時点（2024年1月31日）では査読中である。

本論文は全体として高く評価できるが、いくつかの課題も残っている。例えば、救急搬送件数のデータは患者の初期診断のデータのみである。患者のその後の診断データに基づく分析が行われていない。また、今後の熱関連健康リスクに影響を及ぼす一部の要因（例えば、技術の今後の発展、予測が困難である大きな出来事など）の分析は本論文には含まれていない。さらに、データ不足のために、新型コロナウイルスの影響により熱関連救急搬送件数が減少している要因分析ができていない。

しかし、上述した課題は今後の研究課題であり、本論文の質を大きく損なうものではない。よって、本論文は博士（総合学術）の学位論文として価値あるものと認める。また、2024年1月25日に論文内容とそれに関連した事項について試問した結果、合格と認めた。

要旨公表可能日：　年　月　日以降