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ISSN 2959-6157

Trend of Temperature Change in Shanghai: Long-Term Observations and Driving Factors

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Abstract:

The purpose is to provide suggestions to urban planning activities based on previous data. The topic of this paper is extreme temperature and the temperature changing trend. In the previous research, there is a gap, the gap is that the previous researches only focus on the study of urban areas but ignores the suburban areas around, so it is not very helpful for future urban planning. This research is a literature review, where the research reports made by scientists based on previous studies are examined. Then all the data will be analyzed and presented in tables, using figures to illustrate the findings. The gaps in the research have also been found, so this research then determines what can be improved in order to make it more reliable and more helpful for future development and urban planning. What the research found is that urbanization is very closely related to the rising temperature trend because of the urban heat island effect. The conclusion is that the research should be further strengthened so that the results will be more useful for urban planning in the future.

Keywords: Urbanization, Urban heat island effect, temperature change, extreme event

1. Introduction

Nowadays, the climate change problem affects people a lot. In the Yangtze River Basin, a 120-year dataset (1901–2020) from 10 cities shows a clear temperature increasing trend, especially in the past 40 years [1]. Extreme temperatures in the basin display clear periodic patterns of extreme high temperatures rose in the 1930s, declined until the 1980s, then rebounded. At the same time, low temperatures generally increased before the 1970s and decreased in the past 40 years [1]. The frequent occurrence of extreme weather events displays a significant threat to urban ecosystems, socio-economic operations, and residents' health.

Shanghai has already experienced rapid urbanization, which intensifies the urban heat island effect and alters local climatic conditions. Understanding temperature variation patterns in Shanghai is therefore crucial for both scientific knowledge and urban planning. A study about 28 CMIP5 models' performance in simulating Shanghai's climate, projecting under RCP4.5 (2021-2030), fewer cold nights and more warm nights with low uncertainties [2]. From 1989 to 2013, Shanghai SUHI intensified, and the extremely high temperature area expanded to the south, with the city center being mainly driven by greening and cooling, land use [3]. Compared to coastal cities like Hong Kong, Shanghai shows significant and unique changes in temperature, characterized by an increase in the number of hot days and a decrease in the diurnal temperature range [3, 4]. Research in North China has confirmed that urbanization alters the surface energy balance, becoming a major anthropogenic factor affecting temperature [4]. From a nationwide perspective, metropolitan areas are 'hotspots' for climate warming, with more significant changes in extreme heat event data [5]. Additionally, data from East China between 1961 and 2020 also indicate that higher levels of urbanization correspond to greater rates of temperature increase and larger amplitude of extreme temperature variations [6]. Insufficient observation data and quantitative separation of urbanization effects might still be the shortcomings.

This study will conduct a literature review on the change of temperature in Shanghai based on the background of global warming, and comprehensively analyze and understand the temperature change by integrating past research data. The value of this research is to deepen the understanding of the local climate and provide basic theories for urban planning and related policy formulation to cope with climate change.

2. Climate Change and Urban Thermal Environment in Shanghai

2.1 Shanghai's Climate Trends and Extreme Temperature Events

In the context of global warming, the frequent occurrence of extreme weather events displays a significant threat to urban ecosystems, socio-economic operations, and residents' health. Shanghai, the core city of the Yangtze River Delta, has become a typical example for studying regional climate change responses due to its special geographical location and high level of urbanization. Located at the estuary of the Yangtze River Delta, Shanghai also has a subtropical monsoon climate, characterized by a complex climate system influenced by the East Asian monsoon flow and the temperature differences between the ocean and land. Over the past century, the rise in global temperature has led to significant changes in Shanghai's climate, while rapid urbanization has exacerbated the uncertainty in the local climate system.

Based on meteorological observation data from 1901 to 2020, it has been found that the annual average temperature in Shanghai has shown a significant upward trend. The temperature increasing rate (about 0.24°C/10a) in the past 60 years has far exceeded the previous period. [1] As described in Table 1, the increase in the minimum temperature was higher than the maximum temperature at that time, resulting in the reduction of the temperature difference between day and night. Extreme temperature events occur frequently; at the same time, they represent the characteristics of increasing warm events and decreasing cold events. This characteristic represents the reduction of climate stability.

Table 1. A sample of Shanghai extreme temperature events:

Extreme temperature events in Shanghai	The change in the number of them in the past 40 years
Warm nights (TN90P)	Increase rapidly
Frost days (FD)	Continued decline

This trend is more significant than that of Chongqing, a city in the upper reaches of the Yangtze River, which is a city dominated by mountain tombs, resulting in the strong sensitivity of coastal cities to global warming [1].

Based on observational data from 1901–2020, Shanghai shows a significant upward trend in mean annual temperature. In the past 60 years, the warming rate was about 0.24°C/decade, higher than earlier periods. Extreme temperature events occurred more frequently, with a reduced diurnal temperature range. Such patterns are consistent with other studies comparing Shanghai to cities like Hong Kong and Chongqing, indicating that coastal cities are more sensitive to global warming [5].

The number of warm nights (TN90P) has rapidly increased, while frost days (FD) have continued to decline. Similar trends in extreme temperature indices have been observed across eastern China, highlighting the broader regional impact [6].

2.2 Urbanization and Heat Island Effects in Shanghai

At the same time, 30% of the reason for the change in temperature in Shanghai is urbanization. The increase in heat island intensity at urban sites such as Xujiahui is sig-

ISSN 2959-6157

nificantly higher than in other sections in the suburbs [3]. Urbanization has become a key factor affecting temperature.

Research shows that about 30% of the temperature change is related to urbanization. The urban heat island intensity in central Shanghai (e.g., Xujiahui) is significantly higher than in suburban areas, making urbanization a key factor influencing climate change [7]. Long-term analyses confirm that the urban–suburban temperature difference in Shanghai has increased by ~0.4 °C over the past 50 years, with urbanization accounting for roughly 30% of the observed warming [4].

3. Development Status Classification

3.1 Current Research Overview

According to projections under the RCP4.5 scenario from the CMIP5 global climate model, Shanghai experienced a warming trend of approximately 0.87 °C per decade between 1986 and 2005. From 2021 to 2030, extreme weather events in the city are expected to intensify, with more warm nights and fewer cold nights. The number of cold nights is expected to decrease with low confidence, and the occurrences of warm nights are likely to further increase. Furthermore, it is expected that the mean annual temperature will continue to increase notably, with fewer days of frost. Current results generally suggest that extreme climate in Shanghai is highly associated with the influences of urbanization, but there are uncertain cases resulting from model resolution and observing coverage constraints.

In terms of future scenario prediction, according to the RCP4.5 based on the CMIP5 global climate model, the annual mean temperature in Shanghai from 1986 to 2005 showed a warming trend of 0.87°C/(10a). From 2021 to 2030, Shanghai's extreme weather events will further intensify. The number of cold night days is likely to decrease with the lowest uncertainty, and the number of warm night days will continue to increase [2]. As the prediction, for now, in 2025, the mean temperature has an extremely increasing trend, and the number of frost days decreases. However, current research still has limitations: incomplete observational data and global models of extreme events show low-resolution quantitative results when analyzing the effects of urbanization, resulting in uncertainty in result analysis and prediction of future trends in climate change [3].

3.2 Future Climate Projections

Based on CMIP5 models under the RCP4.5 scenario, Shanghai's warming rate during 1986–2005 was 0.87°C/decade. Projections for 2021–2030 suggest intensified extreme events, with more warm nights and fewer cold nights [2]. However, the models have limited resolution, and quantifying urbanization effects remains challenging.

Research Challenges and Improvements: Insufficient early observational data, requiring integration of more historical records; CMIP5 models have limited ability to simulate extreme events; Urbanization effects lack precise quantification, and classification standards for urban/rural stations are needed.

More work is needed on the development of data integration, model precision, and quantification methods.

Shanghai, as the center city of the Yangtze River delta, shows a typical and complicated performance of climate change in the research. The mean annual temperature in the city has increased considerably over the past hundred years, and intense heat events have gradually occurred more often at the expense of cold episodes, especially in recent decades. Urbanization and the urban heat island contribute to about 30% of this warming, emphasizing their role as one of the dominant factors for regional climate variation [7]. Besides traditional observational analysis, future research could also consider the use of various approaches, such as high-resolution regional climate model simulations, remote sensing to analyze land use and urban expansion, and standardization in classifying urban versus rural meteorological stations [1]. Broadening the scope with these methods, in addition to long-term meteorological data, would develop a fuller picture of detailed activities. Projections under the CMIP5 RCP4.5 projection indicate that Shanghai will face even more warm nights, fewer cold nights, and exacerbated extreme weather events. There are, nevertheless, still limitations, such as limited historical records and the coarse resolution of existing models, and difficulty in quantifying the influence of urbanization. So it needs to improve the accuracy of the meteorological model and unified station classification, as well as combining multiple data sources for more accurate evaluation on regional climate change, which is affected by the two factors, both from nature and human activities.

The same trend has been seen in other Chinese megacities. For example, as inland cities, Beijing and Chongqing both exhibit significant warming trends, but their sensitivities to global warming are different from that of Shanghai due to the difference between inland regions and coastal areas. Southern coastal cities like Guangzhou, Shenzhen have also faced an increasing number of hot nights and extreme precipitation events influenced in part by typhoons. Coastal megacities internationally, such as Tokyo, New York, and London, have recorded similar urban heat island intensities and increasing extreme heat event frequencies seen in Shanghai, indicating the global significance of climate change behaviors observed in Shanghai.

In addition to the conventional observational studies, future research could consider combining different types of data and methods, for example high resolution regional climate models, remotely sensed land use/urban expansion information, or standardized classification of urban versus rural meteorological stations. These methods would be carried out in addition to long-term meteorological measurements and could help elucidate the role of human activity in changing weather patterns. Projections under the CMIP5 RCP4.5 scenarios project regarding the future situation of Shanghai, including that more warm nights and fewer cold ones would occur in this region, as well as an increasing trend in extreme events [2]. However, there are still limitations, such as the lack of long-term datasets, coarse resolution models, and difficulty in interpreting changes related to urbanization. Hence, it is suggested that further studies should focus on enhancing the accuracy of models and setting up uniform station classification standards; carrying out scale comparison research between stations in different cities more widely; as well as taking into consideration multi-source data, which helps to evaluate the joint effects between climate change and human activity on regional climate.

Although much has been learnt about climate change in Shanghai, several knowledge gaps are still present. The few early meteorological records cannot reflect long-term trends accurately. Today, most global climate models (e.g., CMIP5) are at coarse spatial resolution and not capable of well-resolving the extreme events in cities. Furthermore, the impact of urbanization on temperatures cannot be properly accounted for due to a lack of readily available criteria to separate rural from urban reporting sites. In part, the narrow focus is because most of these existing studies concentrate only on Shanghai itself and offer relatively little analysis of the larger Yangtze River Delta or neighbouring urban formations.

Subsequently, it would be necessary to use more historical and multi-source datasets in the future, such as ground monitoring with satellite detection, to enhance the reliability of long-term analysis. Further model development is required to integrate high-resolution regional climate models, including urban canopy schemes, to represent processes of extreme weather more closely for densely developed areas. It is important to make clear classification criteria for urban and rural meteorological stations to differentiate the human activity influence from natural variability. Broadening the scope of research from a single city to a regional level will further enhance our understanding of interactions between urban clusters and their collective modifications to climate systems.

4. Future Outlook

In the future, the research on the trends of climate change in Shanghai needs to focus on three breakthroughs: First, to fix the problem of insufficient early observation data, more historical meteorological records need to be integrated to improve the accuracy of analysis [1]. Second, because of the low resolution of the CMIP5 model, there is a bias in the simulation of the variance of extreme events in Shanghai [2]. The simulation ability of extremely high temperature events can be improved by combining the urban canopy model. Third, in view of the problem of quantitative separation of urbanization effects, a classification standard for urban and rural stations should be established to accurately quantify the impact of urbanization on climate change [3]. Therefore, the integration of long-term observational datasets, optimizing the accuracy of model simulations, and elucidating the impact of natural variability and human activities on the climate in Shanghai are expected to be the fundamental directions of future research, which is of great scientific importance for the formulation of urban climate adaptation strategies.

5. Conclusion

In summary, under the background of global climate change, Shanghai has experienced a notable warming trend, accompanied by increasingly frequent extreme temperature events.

Findings in Chapter 2 indicate that during 1901–2020, the city's mean annual temperature rose by approximately 0.24 °C per decade, with a sharp increase in warm nights and a continued decline in frost days. Urbanization has been recognized as the primary cause of an approximately 30 % warming, due in large part to increased UHII.

Chapter 3 additionally emphasizes that the RCP4. 5 scenario point to a continued increase in temperature and an increase in extreme weather events from 2021 to 2030. Nevertheless, there are still deficiencies in data sources, model resolution and quantitative analysis of urbanisation effects. Addressing these limitations by using better observed data, higher-quality model output and a standard separation of urban and rural stations is necessary for further progress in regional climate studies.

In general, this study highlights the necessity of researching the trends and drivers of temperature change in Shanghai, as well as its significance for urban climate adaptation and sustainable development. Enhanced data integration, simulation modelling and more accurate urban–rural climate classification will all provide increased scientific support for adaption to changing climates risks and the protection of livability in the future.

ISSN 2959-6157

For studies related to future temperature changes in Shanghai, it is necessary to further explore integration of long-term observation datasets and optimization for the simulation accuracy of model, and quantify the effects on urbanization and natural factors. These researches will not only enrich the theoretical system of Shanghai regional climate studies, but also give a scientific basis of support for the city to cope with temperature change, which have an immense practical value in ensuring urban ecological security and residents' living quality.

Authors Contribution

All the authors contributed equally and their names were listed in alphabetical order.

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