Changing trend of temperature in nanjing and its correlation with some human activities in recent 41 years

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Changing trend of temperature in Nanjing and its correlation with some human activities in recent 41 Years

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Abstract. Nowadays, climate change and its following impacts have influence on human life, society, and natural ecosystems in many regions on a global scale. Based on the datasets of temperature and human activities, this research analyses the temperature variation trend in Nanjing from 1980 to 2020 by linear regression and time series decomposition. In addition, by comparing correlation coefficients and multiple linear regression, this research explores the correlation between changing temperatures and human activities in the past 41 years. The results show that the temperature of Nanjing has had an increasing trend in the past 41 years, and the warming amplitude is the largest in the spring. Also, temperature change has a correlation with some human activities, and the correlation between total energy consumption and temperature is the biggest. Thus, the influence of human activities on climate is really important.

Keywords: climate change, Nanjing, temperature, human activities, correlation.

1. Introduction

According to the sixth assessment report of IPCC, since industrialization, the climate system has undergone rapid and unprecedented changes, and human activities have caused the warming of the atmosphere, oceans, and land [1-2]. The current global warming trend is still ongoing, and the earth is getting warmer and warmer. Climate change is perhaps the most profound challenge ever to have confronted human social, political, and economic systems.

Temperature is a fundamental measurement for describing the climate. Under the background of global warming, the average annual temperature in China has significantly increased in the past 100 years [3]. Nanjing is located at 31°14' ~ 32°37' N, 118°22' ~ 119°14' E, in the middle and lower reaches of the Yangtze River. Nanjing has a subtropical monsoon climate with high humidity, abundant rainfall, and four distinct seasons. The summer season is hot and long-lasting, and the winter season is humid and cold. Thus, it also has a typical hilly inland climate. Studying climate change in Nanjing has important reference value for understanding climate change and its characteristics in the middle and lower reaches of the Yangtze River under global warming conditions, and it is also of great significance for investigating the relationship between climate change and human activities [4]. Additionally, Liu et al. show that in recent years, the changing trend of temperature in Nanjing is consistent with the trend of climate change in China and the world, and after 1980, the trend of temperature increase in Nanjing is more obvious. However, further research is needed on more specific factors that affect climate change

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and their response mechanisms [4]. Tang et al. indicate that the possible causes of the increase in temperature in Nanjing are related to the climate change background, and the impact of city size on temperature change is complex and uncertain [5]. Moreover, Fang et al. claim that rapid economic growth has made China face more environmental challenges [6]. Thus, this research chooses Nanjing as the city for exploration.

The four common seasons in China are winter (December, January, February), spring (March, April, May), summer (June, July, August) and autumn (September, October, November). The purpose of this research is to analyze the regional temperature change using the monthly average temperature data, and try to analyze the relationship between human activities and climate change in the region. The datasets of carbon dioxide emissions, industrial wastewater discharge, total energy consumption, total population at year-end, and urban green coverage rate can reflect some human activities to some extent, so this study uses them to make a correlation analysis. This study has scientific significance in understanding temperature changes in Nanjing in recent decades, and provides suggestions and a scientific basis for relevant government departments to make relevant policy recommendations.

2. Methodology

2.1. Monthly temperature data for Nanjing and human activity data

The database of monthly average air temperatures in Nanjing from 1980 to 2020 used in this paper is collected from the NOAA website[7]. The datasets of carbon dioxide emissions and total energy consumption in Nanjing from 2005 to 2020 are obtained from literature from other scholars [8-12]. The datasets of industrial wastewater discharge, total population at year-end, and urban green coverage rate in Nanjing for the period from 2005 to 2020 are downloaded from the EPS (Easy Professional Superior) data platform, and the missing values are supplemented by searching the Nanjing Statistical Yearbook and Nanjing Statistical Bulletin.

2.2. Methods

To explore the changing trend of Nanjing's temperature from 1980 to 2020, this paper adopts linear regression and Seasonal-Trend decomposition procedure based on Loess (STL). The calculation process of STL is as follows: Firstly, the original time series data is smoothed to remove noise and outliers from the data. Smooth processing can use the locally weighted regression algorithm or other similar algorithms. Then, the smoothed data is periodically decomposed into the average level of each season and the seasonal component is calculated. Next, subtract the seasonal component from the raw data to obtain the trend component. This component represents the long-term trend in the data, which may be an upward or downward trend. Finally, subtract the seasonal and trend components from the smoothed data to obtain the residual component. This component represents short-term volatility and randomness in the data.

In order to investigate the relationship between human activities and regional climate change, the author calculates the correlation coefficients between the datasets about human activities and temperature, and performs multiple linear regression analysis. Correlation analysis can study the relationship between variables, that is, whether there is a relationship and the degree of closeness of the relationship. The correlation coefficient is a statistical measure that describes the strength of the relationship between the two variables. The values range between -1.0 and 1.0. The closer the value is to 1.0 or -1.0, the stronger the correlation. The closer the value is to 0, the weaker the correlation.

3. Results

3.1. The analysis of the changing trend of temperature

As Figure 1 shows, the annual average temperature in Nanjing from 1980 to 2020 was 15.7049 Celsius degrees. It can be observed from the curve in Figure 1 (a) that Nanjing has shown a warming trend in the past 41 years and the temperature will continue to increase in the next five years. Figure 1(b)

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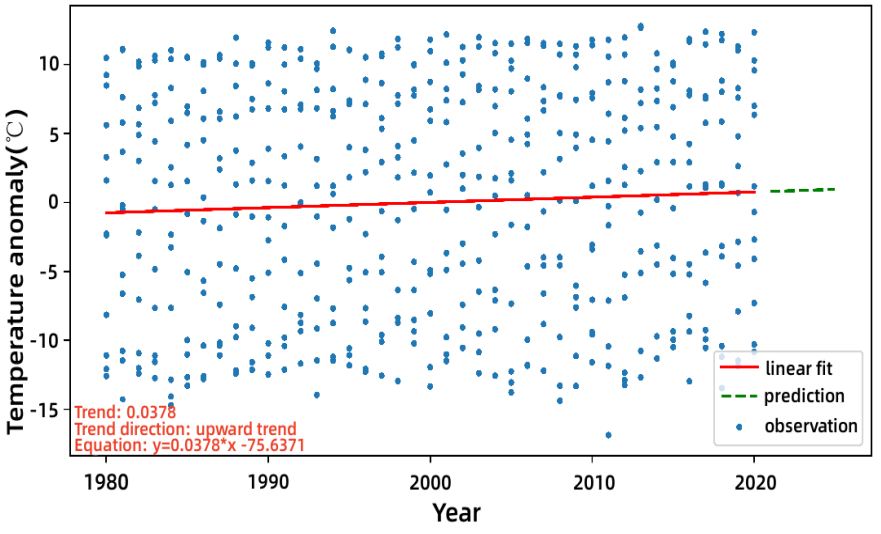
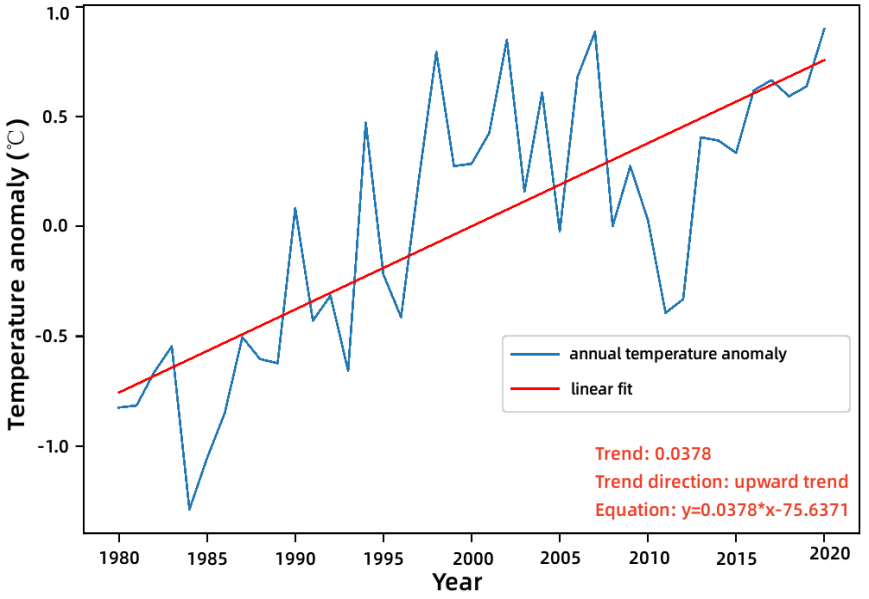
indicated that temperature anomalies were mainly negative before 1990, and mainly positive from 1990 to 2020. According to the linear regression equation, the linear growth rate of annual average temperature is 0.0378 Celsius degrees per year, positive value, representing that the temperature change in Nanjing has shown an increasing trend in the past 41 years. According to the simple linear regression model, the linear fitting analysis can be obtained that the average annual temperature growth rate of Nanjing over the past 41 years is about 0.378 Celsius degrees per decade, and the warming amplitude is about 1.5498 Celsius degrees.



(a)



(b)

Figure 1. Air temperature anomalies of Nanjing and their trends (1980 to 2020): (a) Monthly average; (b) Annual average.

As shown in Figure 2, the average temperature in Nanjing during 41 years was 15.0272 Celsius degrees in spring (Figure 2a), 25.7564 Celsius degrees in summer (Figure 2b), 17.3743 Celsius degrees in autumn (Figure 2c), and 4.6618 Celsius degrees in winter (Figure 2d). Based on the linear fitting analysis, it can be inferred that during these 41 years, the linear growth rate of the average spring temperature was 0.587 Celsius degrees per decade, that of summer was 0.292 Celsius degrees per decade, that of autumn was 0.329 Celsius degrees per decade, and that of winter was 0.305 Celsius degrees per

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decade. Both of them are positive values, indicating that the temperature change in Nanjing in all four seasons from 1980 to 2020 shows an upward trend. The warming amplitude of average temperature in Nanjing is the largest in spring, followed by autumn and winter, and the smallest in summer. They are 2.4067 Celsius degrees, 1.3489 Celsius degrees, 1.2505 Celsius degrees, and 1.1972 Celsius degrees, respectively.

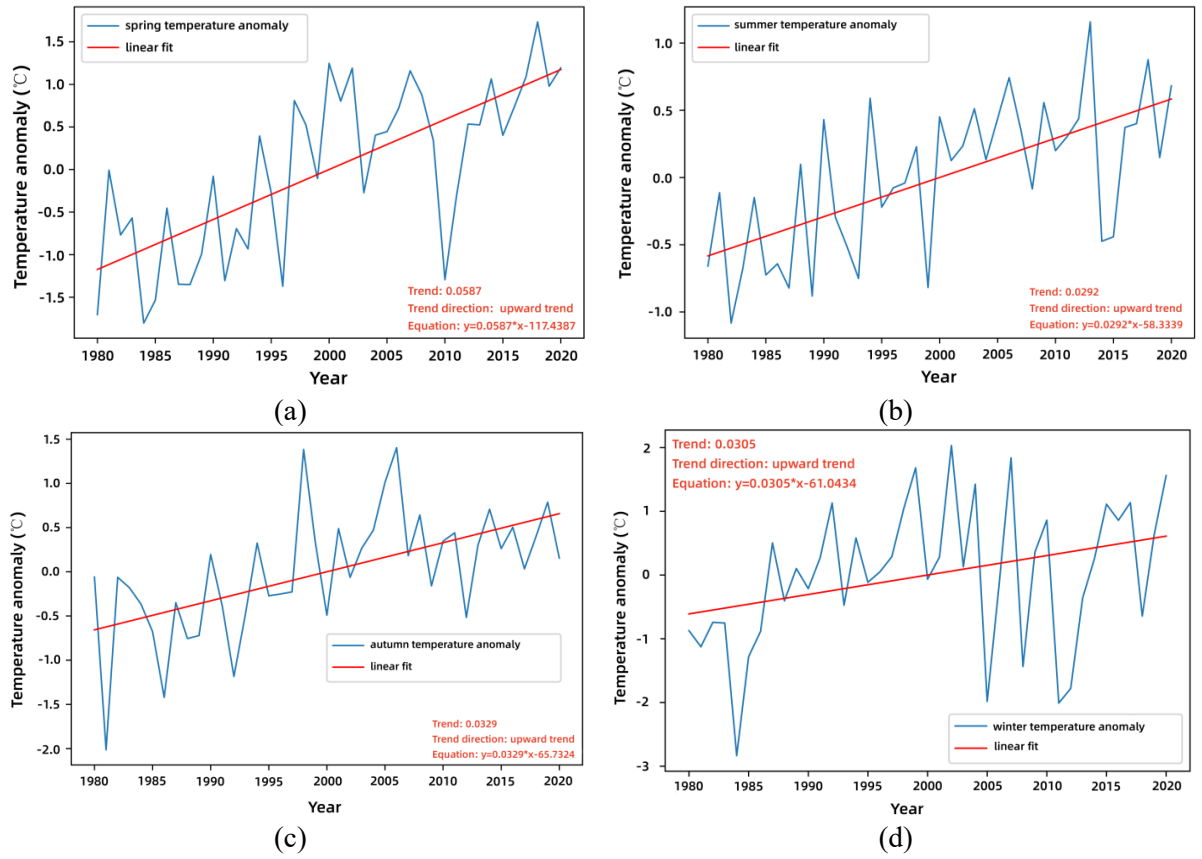

Figure 2. Average air temperature anomalies of Nanjing and their trends from 1980 to 2020 for (a)spring (b)summer (c)autumn and (d)winter.

From Figure 3 (b), it can be seen that the trend of temperature change from 1980 to 2020 has roughly increased, with a significant upward and continuous trend. In 1984, the trend reached its minimum value of approximately 14.2, and in 2020, it reached its maximum value of approximately 17.1, during which time the temperature rose the fastest. There was a significant 2-4 year oscillation in the temperature trend between 1990 and 2010, which tended to flatten out from 2010 to 2013, and the oscillation intensified after 2013. Figure 3 (c) shows the seasonal cycle, which uses 12 months as the window for seasonal analysis. It can be seen that there is a very significant interannual oscillation in this time series. Figure 3 (d) shows the trend and seasonal remaining values separated from the time series. It can be observed that most of the residuals are concentrated between ± 2.5, with only a few large outlier. Therefore, the noise of the time series has little impact on the analysis of trends and seasonal cycles.

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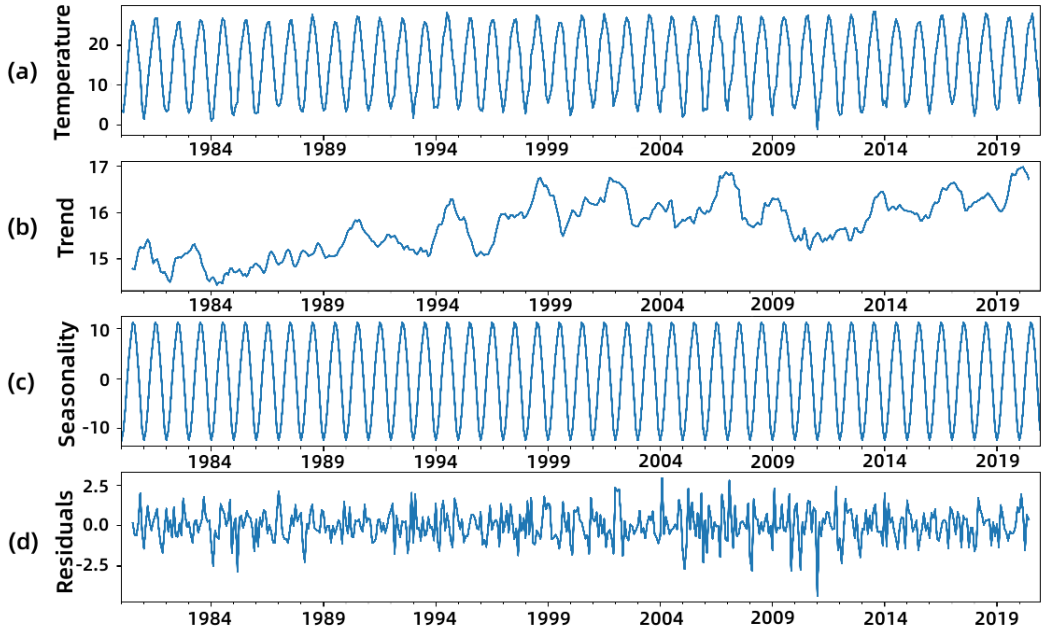

Figure 3. STL time series decomposition of monthly average air temperature in Nanjing from 1980 to 2020: (a) the time series of temperature; (b) the trend obtained after decomposition; (c) the seasonal period after decomposition; (d) the residual after decomposition.

3.2. The analysis of the correlation

The author divided the time series into two parts. One is the period from 1980 to 2004, and the other is the period from 2005 to 2020. Because of the implementation of reform and opening up policies in China since about 1978, the speed of China's industrial and economic development has greatly increased, and the industrial production capacity has also been constantly increasing. The great decision to reform and open up in 1978 led to the rapid development of China's industry with unprecedented vitality. Over the past years, China has established a modern industrial system with a complete range of industries, and has become a truly global manufacturing power. In 2017, the industrial added value approached 28 trillion yuan, which is 53 times higher than 1978 at comparable prices, with an average annual growth rate of 10.8%. However, the rapid development will cause more industrial gases, greenhouse gases, and pollutant emissions, further exacerbated by global warming. With the advancement of urbanization in Nanjing, the built-up area in the urban area expanded from 121 square kilometers in 1985 to 513 square kilometers in 2005. Thus, the urban green areas have decreased, and biodiversity has decreased, which directly affects the temperature change in Nanjing [4, 13]. Human activities have a correlation with climate change in Nanjing and have an important influence on global warming.

For the period 2005-2020, this research used Python to do data analysis. Figure 4 is the histogram of the correlation coefficients between some impact factors and the temperature. The impact factors chosen to talk about in this research are carbon dioxide emissions, industrial wastewater discharge, total energy consumption, total population at year-end, and urban green coverage rate. Figure 5 is the curve of multiple linear regressions of the temperature and impact factors from human activities. The independent variable is year, and the dependent variable is temperature (unit: Celsius degree). The green line is the smoothed temperature, which can provide more accurate and reliable data analysis results, helping to understand and interpret the patterns and trends behind the data.

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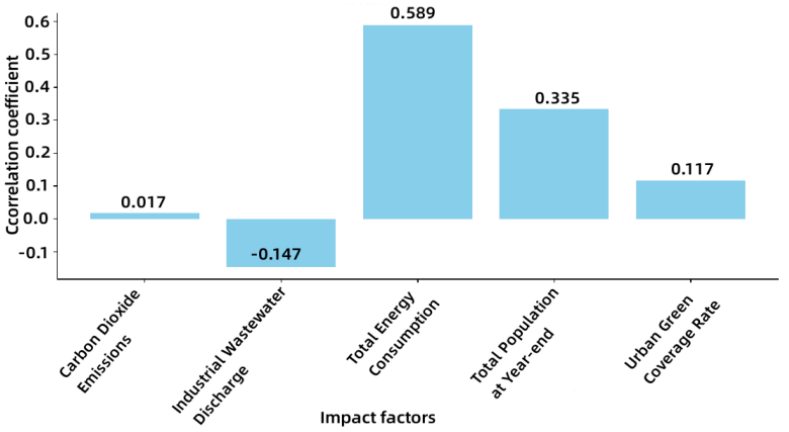

Figure 4. Correlation coefficients between some impact factors and the temperature of Nanjing from 2005 to 2020.

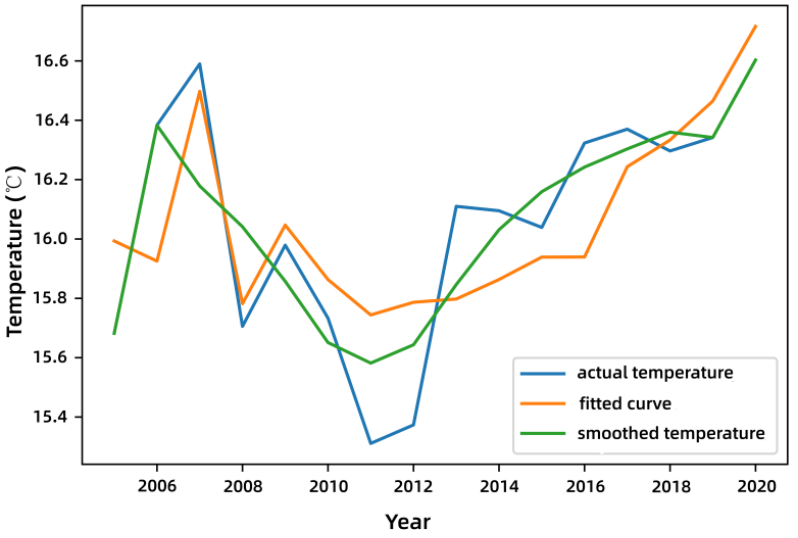

Figure 5. Multiple linear regression of the temperature and impact factors from human activities.

From Figure 4, it can be observed that the correlation coefficient between total energy consumption and temperature is the highest, reaching approximately 0.589, indicating a strong positive correlation. The correlation between the year-end total population and temperature is also significant, with a coefficient of around 0.335, showing a positive relationship as well. Also, energy consumption and emissions are closely associated with population size and economic growth [6]. It is likely that energy conservation and emission reduction policies were implemented before 2005 due to ongoing global warming. Consequently, the correlation coefficients between carbon dioxide emissions/industrial wastewater discharge and temperature are relatively small. The negative coefficient for industrial wastewater reflects a decrease in its discharge, highlighting the effectiveness of the policies.

In Figure 5, from the five-point smoothed curve, it is evident that the temperature in the Nanjing region shows a significant upward trend year by year, with the rate of increase gradually getting higher. Also, the degree of influence of some human activities on temperature is in order of urban green coverage rate, carbon dioxide emissions, total population at year-end, total energy consumption and industrial wastewater discharge. However, attributing observed warming to a specific human forcing still has significant uncertainty [1-2].

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4. Suggestions

The rising temperature in Nanjing could be seen as a microcosm of global and national warming trends. Global climate change is a worldwide challenge that has significant impacts on both human society and ecosystems. As one of the important cities in China, Nanjing's temperature trend reflects characteristics consistent with global climate change. This not only directly affects the lives and health of local residents but also poses challenges to agriculture, water resources, and the ecological environment.

Therefore, proactive measures are needed to address the challenges posed by rising temperatures. The analysis indicate that there is a strong positive correlation between total energy consumption and temperature. Thus, the government should put a greater emphasis on the promotion of new energy sources like solar energy, wind energy, and ocean energy, and reduce reliance on traditional fossil fuels, thereby improving the cleanliness and sustainability of the energy structure. At the same time, energy-saving and emission reduction can be encouraged to improve energy efficiency, while promoting low-carbon lifestyles to reduce greenhouse gas emissions. In addition, as the urban green coverage rate has a correlation with temperature change, efforts can be made to strengthen vegetation conservation, actively engage in afforestation initiatives, and avoid excessive logging and vegetation destruction. Furthermore, governments should enhance the formulation and enforcement of environmental protection regulations to provide strong support for addressing climate change.

5. Conclusion

The monthly average temperature of Nanjing from 1980 to 2020 had an increasing trend, and there would be a similar trend in the future. And according to the analysis, there is a positive correlation between human activity and temperature rise, meaning that human activities affect the changes in temperature. The phenomenon of rising temperatures in Nanjing is also a reminder of the urgency of global climate change. Climate change can be mitigated by taking actions to reduce greenhouse gas emissions, e.g., by saving energy, thereby creating a sustainable world for the future. However, there are also some limitations to this research. Firstly, the data volume is not large enough, especially the data related to human activities, which was selected only from 2005 to 2020 due to the limited records. Secondly, the research only focuses on the Nanjing region, and the representativeness of the calculation in the correlation study is not significant enough. In future research, some optimizations need to be made, such as analyzing meteorological data and human activity data for a larger region, and expanding the year range covered by the data.

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