Predict the frequencies of cold waves in Guangdong in the future using CanESM5 Model

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Abstract. In this research, we used the data of daily minimum temperatures from ensemble r1i1p1f1 of CanESM5 model under the five SSP scenarios, namely SSP 1-1.9, SSP 3-7.0, SSP 4-3.4, SSP 4-6.0 and SSP 5-8.5, to calculate the frequencies of cold waves in Guangdong from 1900 to 2100, in order to make an accurate forecast of the pattern of occurrences of cold waves in Guangdong for the foreseeable future and compare it with the situations in the past. The frequencies of cold waves in Guangdong generally stayed stable at 4 from 1900 to 2014, though a slightly decline trend still can be witnessed. The frequencies of cold waves under the scenario SSP1-1.9 will show a decline trend at the beginning, but they will remain and finally increase in the mid and late twentieth century, while the frequencies of cold waves under the scenarios SSP 3-7.0, SSP 4-3.4, SSP 4-6.0 and SSP 5-8.5 will generally all decline in the future. The trends of frequencies of cold waves varied in different regions of China in the past, and the decline trend in northern China was significant than that in southern China.

Keywords: Cold waves, Guangdong, CanESM5.

1. Introduction

During the cold season, a cold wave is a discrete period characterized by a sudden, significant drop in temperature [1]. If the level of the cold air is greater than the level of the cold wave, a widespread cooling effect will be produced, which may cause severe harm to agricultural productivity [2]. Not only can a severe cold wave be detrimental to agriculture, but it can also affect human mortality. It was revealed that cold waves were associated with an increase in the mortality rate in Japan due to a range of causes. Since the agricultural level of Guangdong Province is important to China, and the public health is also important to society, it is significant to predict the frequency of cold wave in Guangdong Province in the future [3].

Although the significant increase of global temperature, many researchers found that this phenomenon does not reduce the occurrence of cold waves, both now and in the future. It has been demonstrated that the occurrence of severely cold episodes has increased significantly since 2006. [4]. In China, this is mainly caused by the loss of Arctic Sea ice [5]. Because of different places which different studies focused on, the research findings of characteristics of cold wave were different. It found that the number of times that a cold wave has occurred in the low latitudes of East Asia showed a decline trend, which is different from the circumstances in the high latitudes [6].

Rajulapati et al. (2022) found that the cold waves will reduce in some cities of Canada in the future, but the reduction in cold waves the future is evident regardless of the temperature; more precisely, the average rate of decline is virtually identical across all scenarios [7]. By using CMIP5 and CMIP6 model ensembles, Freychet et al. (2021) showed that in southeast China, it is projected that the frequency of protracted periods of cold weather will decline dramatically during the next several decades [8].

In this research, we used the data of daily minimum temperatures from ensemble r1i1p1f1 of CanESM5 model under the five SSP scenarios to calculate the frequencies of cold waves in Guangdong from 1900 to 2100, in order to make an accurate forecast of the pattern of occurrences of cold waves in Guangdong for the foreseeable future and compare it with the situations in the past.

2. Data and Methods

CanESM5 is a worldwide scale, a model of the Earth's system that was built by the Canadian Centre for Climate Modelling and Analysis (CCCMA) of Environment and Climate Change Canada (ECCC) to develop seasonal and interannual climate forecasting, research the climate of the past and create projections for the climate on a century-long timeframe. The most recent version of CCCma's coupled GCM, CanESM5, incorporates minor modifications to the models for the atmosphere, land surface, and terrestrial ecosystems [9]. The initialization technique entails a critical instrument of varied initial states for the water and distinct disturbances for the atmosphere; consequently, each member mimics a unique revelation of the internal-variability. We selected the ensemble member of CanESM5 model to predict the frequencies of cold waves in 5 different future scenarios, namely SSP1-1.9, SSP3-7.0, SSP4-3.4, SSP4-6.0 and SSP5-8.5. Moreover, according to the location of Guangdong and the grids of the model, we selected the frequencies of cold waves on a grid, namely 23.72°N, 115.31°E, to present the frequencies of cold waves in Guangdong.

According to the definition of cold wave: If the minimum temperature of a place in 24 hours is decreased equal or more than 8 degrees Celsius near surface compared to yesterday, or it is decreased equal or more than 10 degrees Celsius in 48 hours, and the minimum temperature is less than 5 degrees Celsius near surface, then we consider a cold wave event happens. Therefore, we chose 2 m as the near surface height and extracted the daily minimum temperature states from 2015 to 2100 in five scenarios from CanESM5 Model. We found the history data of the minimum daily temperatures of Guangdong from 1900 to 2014 as well. Then, we calculated the frequencies of cold waves happening in each year from 1900 to 2100 according to the definition of cold wave. Finally, we smoothed the data to draw the trend lines for each scenario.

After obtaining the annual frequency of cold waves from 1900 to 2100, we will use the statistical methods of time series data to create different models to predict the frequency of cold waves and finally select the best one. The theoretical and application effects of each method will be described in detail in subsequent chapters.

From Figs1 a, b, c, d, and e, we can see that the frequencies of cold waves in Guangdong generally stayed stable; namely, 4, though with fluctuation. Although their trend of them was not significant, a slight decline trend in the frequencies of cold waves can still be witnessed, especially in the last decade.

According to Fig1. a, if the scenario is under SSP1-1.9, the frequencies of cold waves in Guangdong will slightly stably reduce in the future from about four. They will maintain at about 3 in the early and mid-twenty-first century. However, the frequencies of cold waves will show an increasing trend in the mid and late twenty-first centuries. Therefore, we assume that if we can keep the SSP1-1.9 scenario in the future, the frequencies of cold waves in Guangdong will eventually rise to the same level as now, which probably means the global warming issue will get a lot better.

Figs1. b, c, and d show a stable, consistent trend of future deducting numbers of cold waves in Guangdong. The circumstance under scenario SSP4-3.4 is the most stable one among the three. Under the scenario SSP4-6.0, the frequencies of cold waves will decrease the fastest among them. The circumstance under scenario SSP3-7.0 is in the middle between them. No sign shows that these three trends will significantly increase in the future, but they are relatively stable and acceptable in some way. It might mean the global warming issue will still happen and get a little bit worse, but it will still be manageable.

For scenario SSP5-8.5 (Fig1. e), this situation will become more dramatic than any other. It shows that the frequencies of cold waves in Guangdong will consistently decrease at a relatively fast speed from about 2040, and they will not stop this trend until latter decades of the 21st century. At the end of the century, they will drop to about 2. This probably means that maybe 30 years later, global warming will become a big problem for humans.

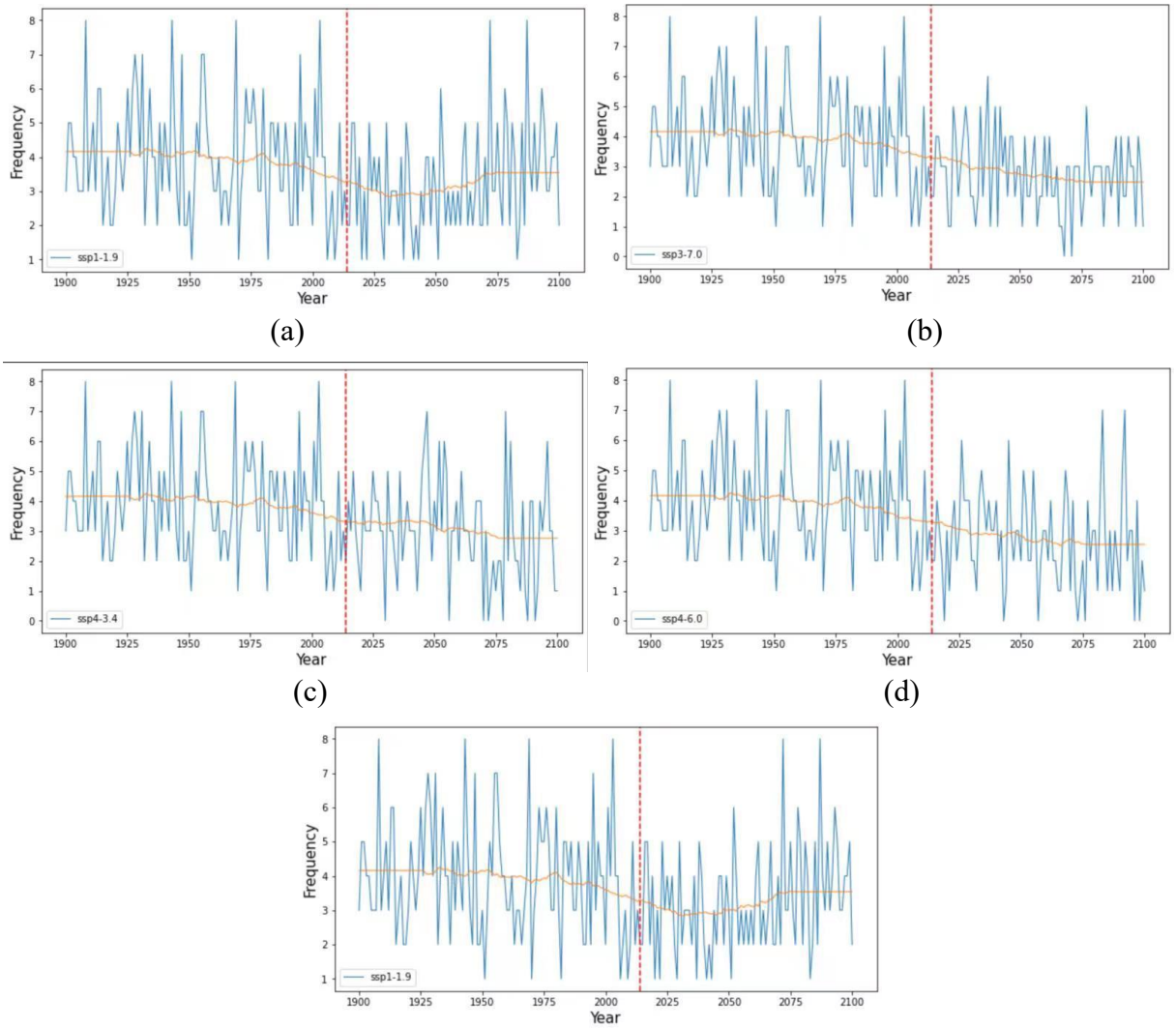


Fig. 1 The frequencies of cold waves from 1900 to 2100 in the 5 scenarios (The orange line represents the trend line, and the red line represents 2014.)

A time series is often a Secular trend, Seasonal Variation, Cyclical Variation, or Irregular Variation, the superposition or coupling of four types of various forms. Secular trend refers to the basic tendency of a phenomenon to develop and change in a particular direction over a considerable period. By analyzing the long-term trend of a phenomenon, it is possible to determine the direction, rate, and pattern of the development, as well as the accurate trend line, all of which are conceivable. There are linear and non-linear trends in the form. Seasonal changes are the cyclical fluctuations of socio-economic phenomena influenced by natural conditions, social customs, and other factors that occur during the year with the change of seasons. Cyclical fluctuations are oscillatory or wave-like movements surrounding a long-term trend in a time series. Typically, cyclicity is a result of business and economic activity. It is not a continuous movement in a single direction, but rather oscillations between increases and decreases. Irregular waves are also called random waves. Periodic fluctuations occur randomly, with varying wave heights, periods (wavelengths), and directions.

The time series data decomposition plots of 5 scenarios are shown below, from which the frequency pattern of cold wave occurs gradually upward due to the coupling effect of global warming and various environmental factors, and the periodicity is about 10-12 years cycle.

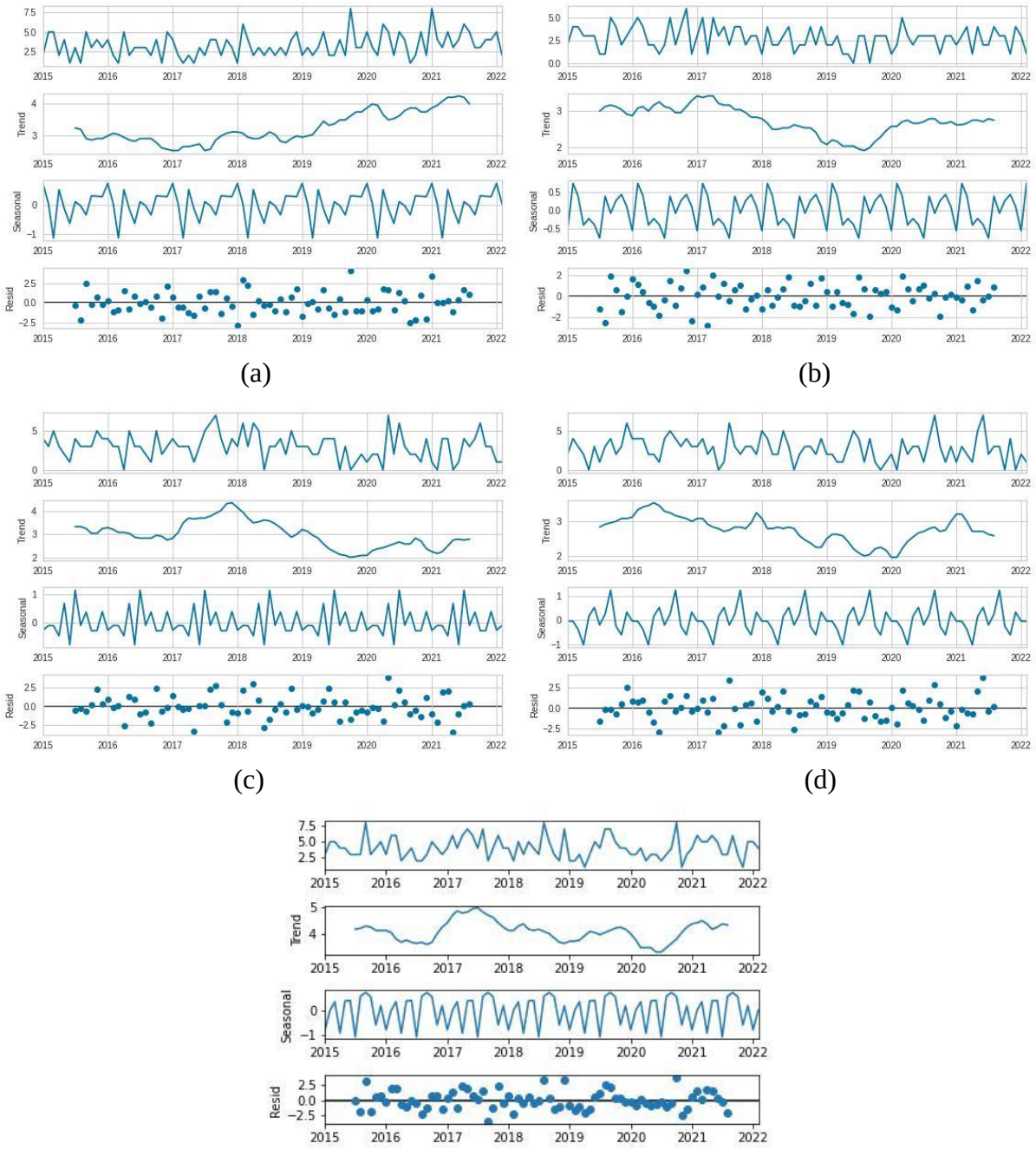


Fig. 2 The decompose Chart in the scenario of 5 scenarios (The orange line represents the trend line, and the red line represents 2014.)

3. Moving average method

Using a straightforward tool called a moving average can help to make projections more accurate. Based on item-by-item data from a time series, it is a technique for computing the consecutive averages of a specific number of words in order to reveal long-term trends. As a result, when the value of a time series is influenced by cyclical changes and random fluctuations, the moving average method can reduce their influence and guide the movement of the event (i.e., the trend line), which can then be studied to anticipate the long-term trend of the series. In other words, the moving average method can reduce the impact that cyclical changes and random fluctuations have on the value of a time series.

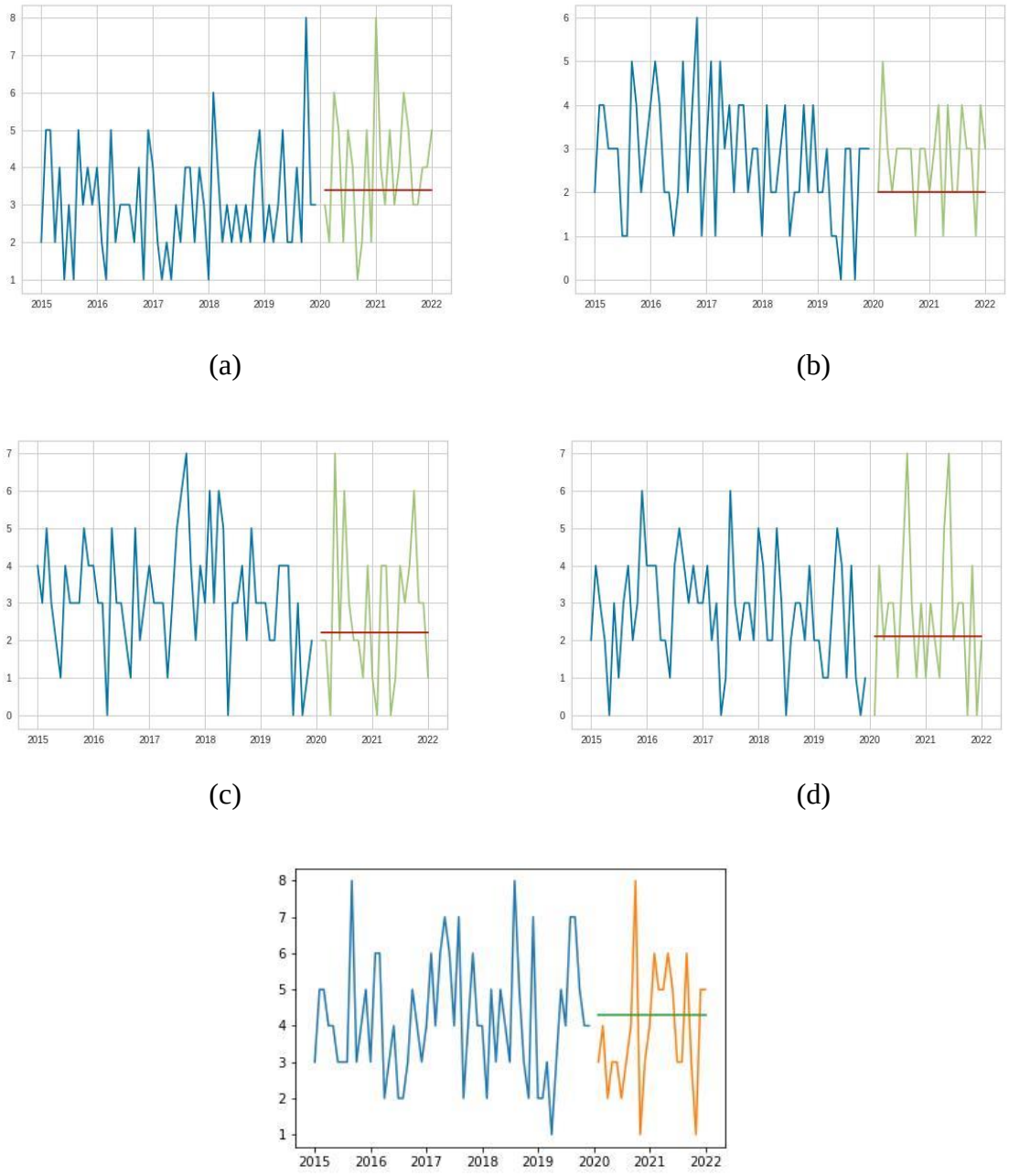


Fig. 3 a-e The Moving Average Method Forecast and Effectiveness Verification Chart in the 5 scenarios (The orange line represents the trend line, and the red line represents 2014.)

In this study, moving averages were used in 5 different scenarios. It can be seen that the moving average method has some benefits, but it is still too simple for the problem of cold wave frequency.

4. Holt linear trend method

Holt linear trend model, considers the trend of the collected data, i.e. We observe that the simple and weighted moving average methods approach the selection of time points in very various manner: the simple average method uses all past data equally and does not omit any, whereas weighted moving average method disregards more distant data and gives greater weight to the most recent period.

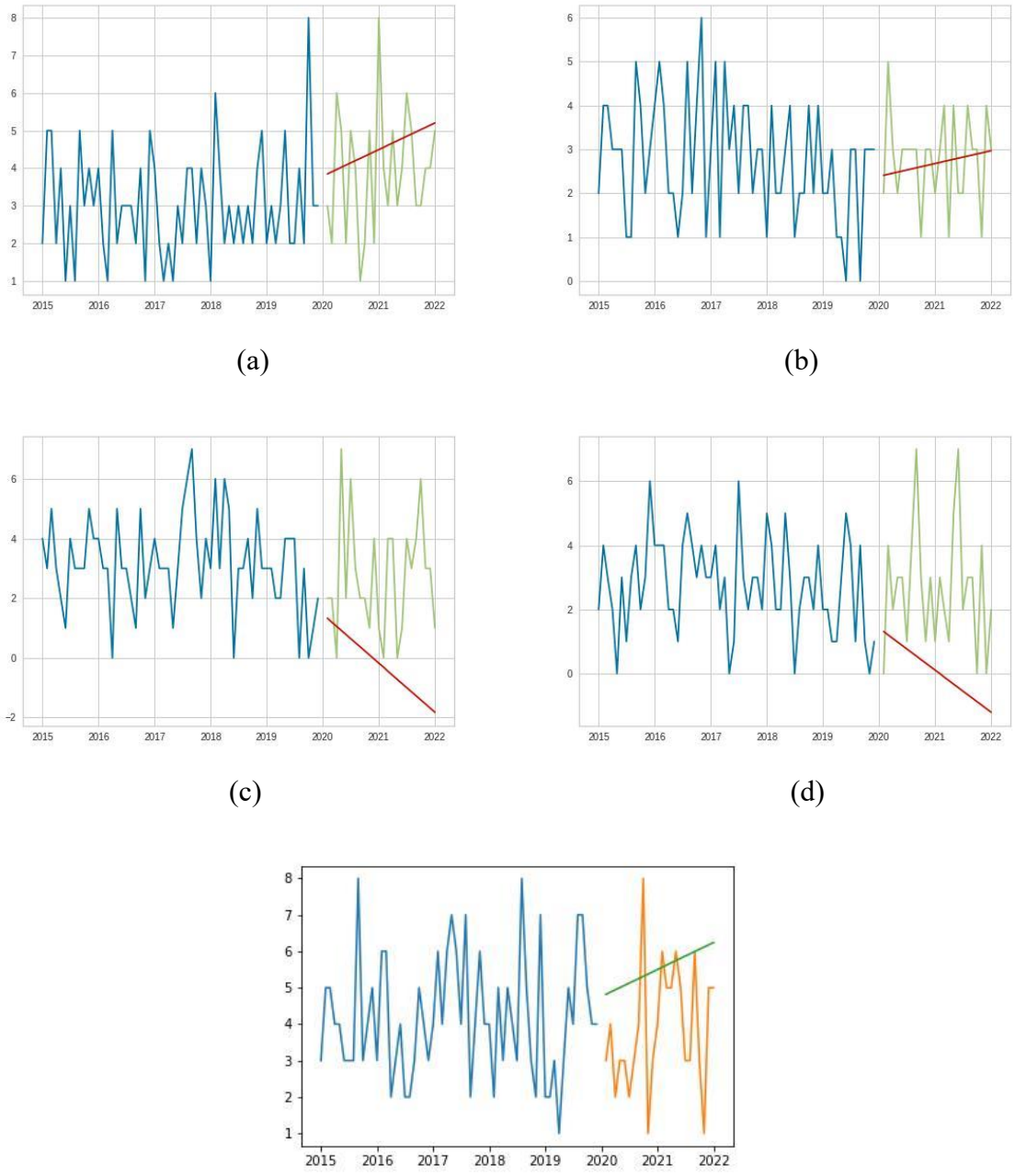


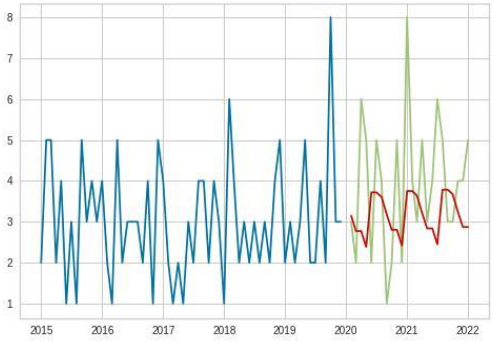
Fig. 4 The Holt linear trend method Forecast and Effectiveness Verification Chart in the scenario of 5 scenarios (The orange line represents the trend line, and the red line represents 2014.)

The exponential smoothing method gives more weight to more recent data and observations while giving less weight to more recent observations in comparison to those from earlier periods of time. It accomplishes this by calculating the predicted value using a weighted average and the earliest references having a negligible impact on the final result. Although each of these ways can be used to identify a trend, the basic averaging method assumes that the movement between the most recent two locations will continue. Alternately, we can derive an average trend by averaging the slopes between all the points, utilizing a moving trend average, or employing an exponential smoothing procedure.

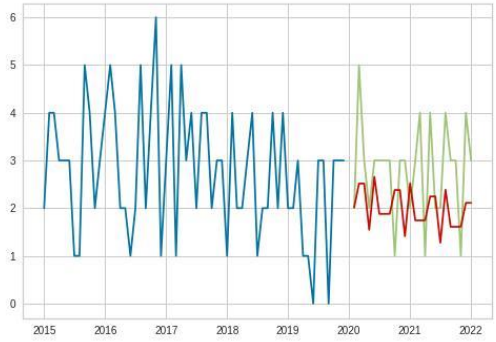
The comparison of the prediction and validation effect of the Holt linear trend method for 5 different scenarios is shown below, from which it can be seen that the Holt linear trend method has some improvement over the moving average method in terms of prediction by trending the frequency of cold wave occurrence effectively reduces the prediction error rate.

5. Holt-Winters method (cubic exponential smoothing)

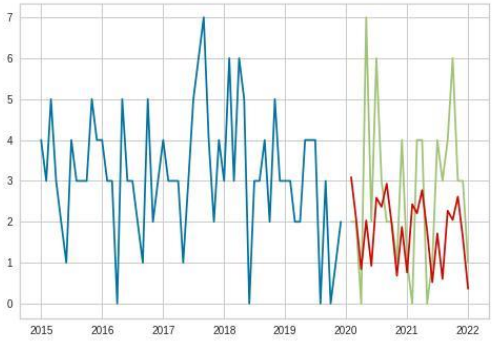
The Holt-Winters method for conducting time series analysis and producing forecasts was created in the 1960s. This approach is effective for analyzing nonstationary time series with both linear trends and periodic variations. Non-stationary time series are the most suitable candidates for this technique. It accomplishes this by adopting a technique known as exponential smoothing (EMA), which enables the model parameters to continuously modify in response to changes in non-stationary series and also enables it to provide short-term predictions of future trends. On the basis of the Holt model, the Holt-Winters method generates a Winters periodic term, also known as a seasonal term. This expression can be used for monthly data (period 12). The Holt-Winters technique, which is based on the Holt model, includes a Winters period term, often known as a seasonal term. Non-stationary series with linear trends and fixed periods can be analyzed using the Holt-Winters method. This approach is decomposable into additive and multiplicative models. The additive model assumes that the trend and seasonal components of the time series xt are additive. This is indicated by the equation xt = ut + st, where ut is shorthand for the trend over period T and st is shorthand for the seasonality over period T. A series is considered seasonal if it repeats a particular pattern at each fixed interval, which is known as a seasonal feature.



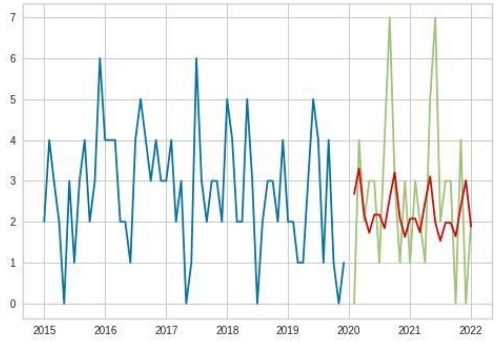
(a)



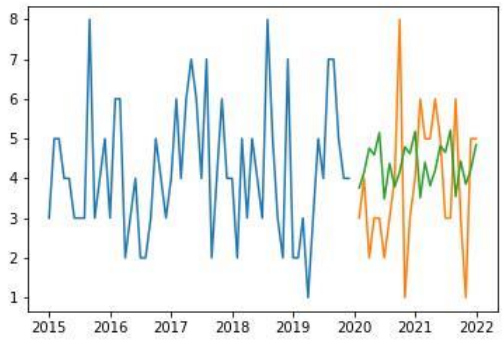
(b)



(c)



(d)



(e)

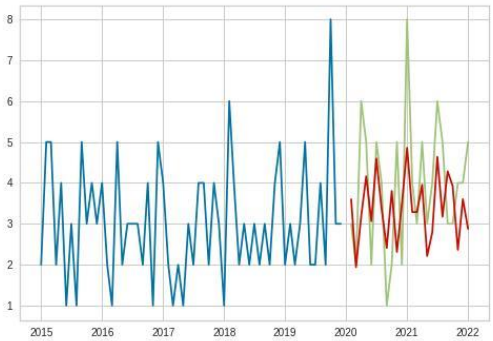
Fig. 5 The Holt-Winter method Forecast and Effectiveness Verification Chart in 5 different scenarios (The orange line represents the trend line, and the red line represents 2014.)

The prediction and validation effects of the Holt-Winter method for 5 different scenarios are compared as follows, from which it can be seen that the Holt-Winter method effectively reduces the prediction error rate by predicting two key factors, the trend of cold wave frequency and the seasonality of the time series, and is better than the Holt Linear trend method has some improvement in prediction again.

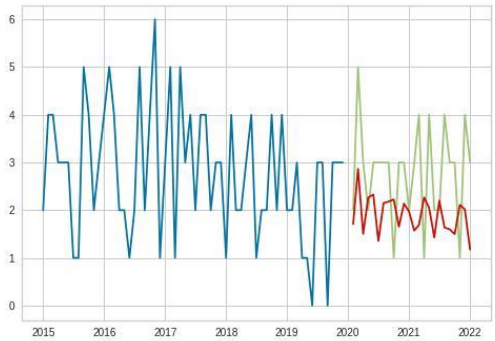
6. Seasonal Time Series Model (SARIMA)

In some time series, there is a significant cyclical variation. Such cycles are caused by seasonal variations (including quarterly, monthly, weekly, etc.) or other inherent factors. This type of series is called seasonal series. Seasonal time series are even more common in the economic or meteorological field, such as quarterly, monthly, weekly, etc. Here, we focus on quarterly and monthly time series. There is a variation in the series with a cycle of 4 quarters. In the 4th quarter of each year, the amount of GDP is much higher than the other quarters due to the influence of the close to the end of the year. The model describing this series type is called the seasonal ARIMA model, denoted by SARIMA. The seasonal time series model is called the multiplicative seasonal model (MSM). model.) This is because the model's final form is expressed as a multiplication of factors.

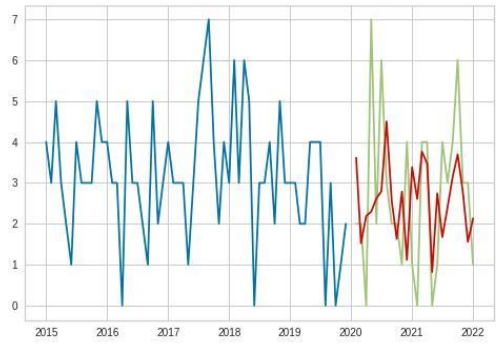
The prediction and validation effects of the seasonal ARIMA model for 5 scenarios are compared as follows, from which it can be seen that the seasonal ARIMA model effectively reduces the prediction error rate by predicting cold wave frequency trends and seasonal variations (including quarterly, monthly, weekly, etc. variations) or some other inherent factors in prediction, which effectively reduces the prediction error rate and is the most effective among all the model methods used.



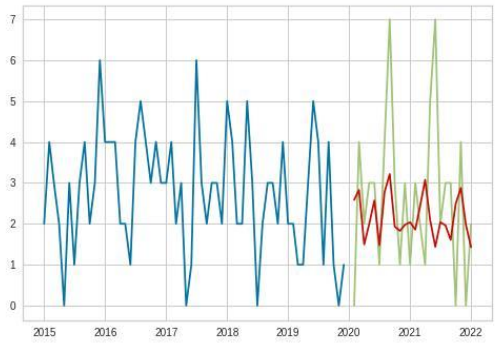
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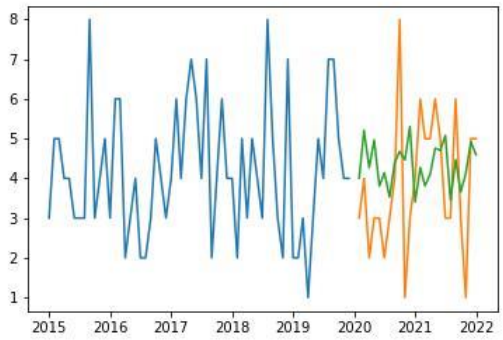
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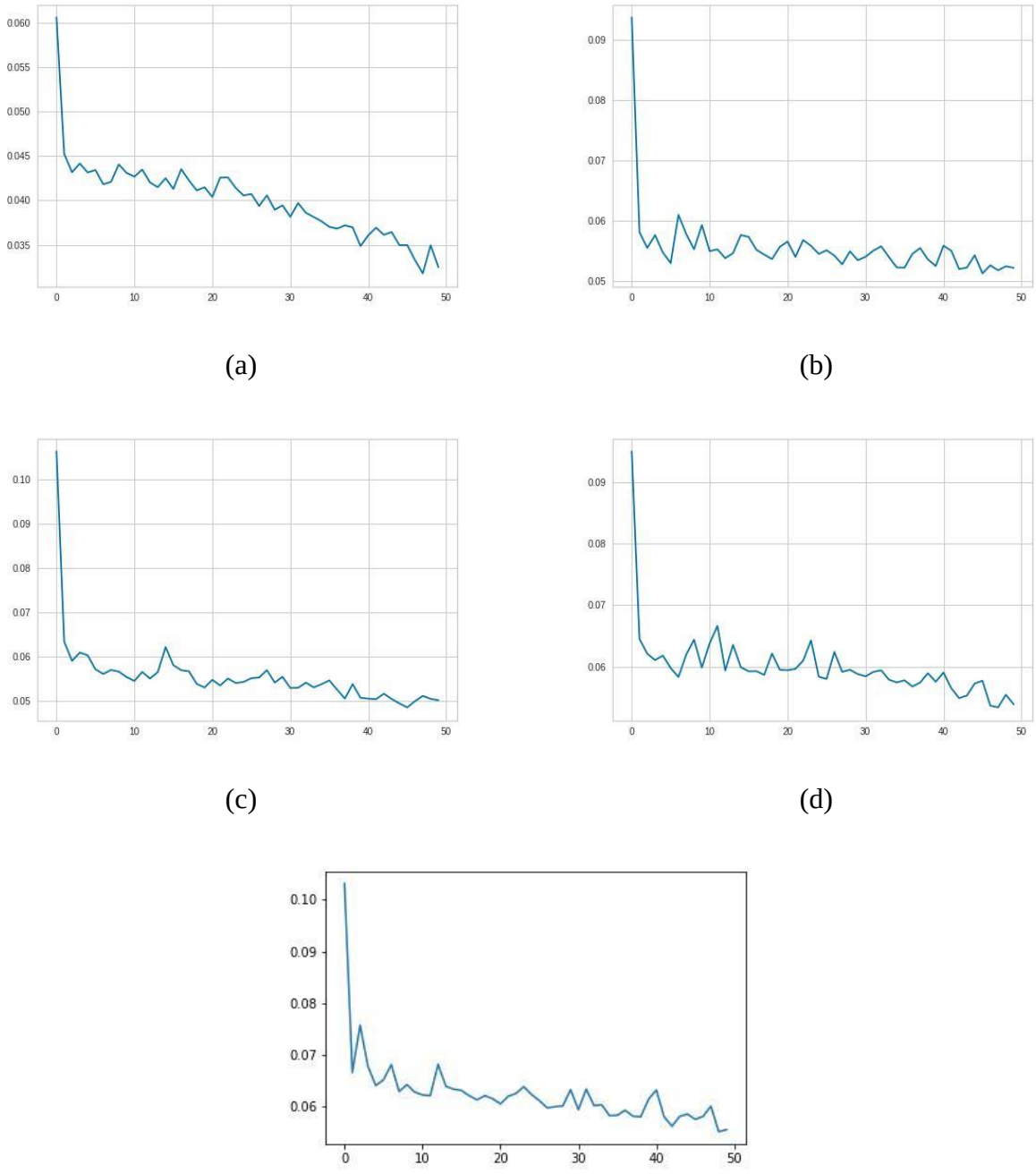
(e)

Fig. 6 The seasonal ARIMA model Forecast and Effectiveness Verification Chart in the 5 different scenarios (The orange line represents the trend line, and the red line represents 2014.)

7. Long Short-Term Memory (LSTM)

Long Short-Term Memory, also known as LSTM, is an example of a chronological recurrent neural network that was developed to solve the issue of long-term dependence that plagues general recurrent neural networks (RNNs), all of which feature a chained form of repetitive neural network modules. This is the difficulty that LSTM was created to solve, hence its name. The structuring of this repeating structural module in a standard RNN is basic. 1997 was the first year that the Long-Short Term Memory (LSTM) article was published. LSTM is well-suited for the processing and forecasting of key events that are separated by huge intervals and time series delays because to its unique architectural structure.

LSTM performs substantially better than temporally recurrent neural networks and Hidden Markov Models when it comes to identifying unsegmented continuous handwriting, for instance (HMMs). In 2009, the ICDAR handwriting recognition contest was won by a model based on the LSTM artificial neural network.



(a) (b)

(c) (d)

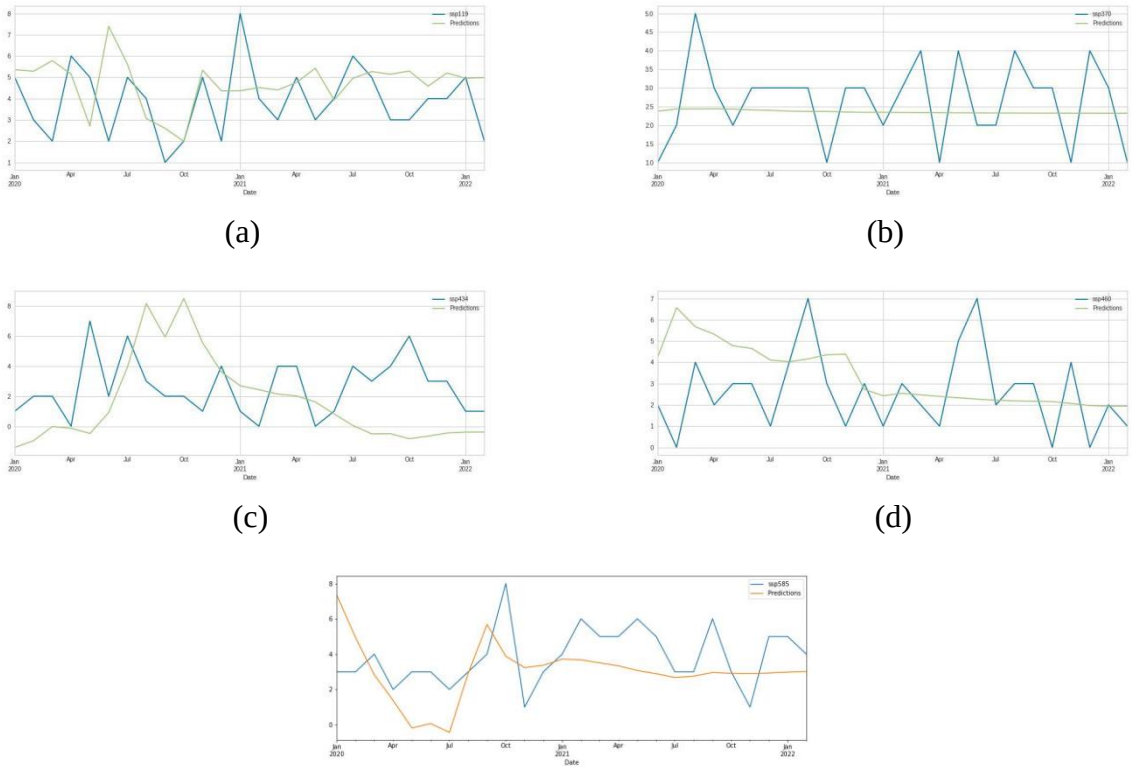
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Fig. 7 a-e The Loss Function Curve Chart in the 5 scenarios (The orange line represents the trend line, and the red line represents 2014.)

LSTM is a type of neural network that may or may not include extra neural network blocks. In the research literature and other sources of information, LSTM blocks are sometimes referred to as intelligent network units due to their ability to keep values for varied durations of time. One of the gates in the block determines if the input is substantial enough to be acknowledged and if it can be output.

At the bottom of Figure 1, it's a total of four S-function units. The input gate is the second function on the left; if the output is very close to zero, the value will be blocked and will not go to the next level. The function that is furthest to the left could wind up being the block's input depending on the conditions. The entrance that has been overlooked can be found in the third spot from the left. If this causes a value to be generated that is extremely close to zero, the value that was previously saved in

the block will be thrown away. The output gate is located on the far right of the fourth input, and it is responsible for determining whether or not the data stored in the block memory may be output.



(a) (b)

(c) (d)

(e)

Fig. 8 a-e The LSTM model Forecast and Effectiveness Verification Chart in the 5 scenarios (The orange line represents the trend line, and the red line represents 2014).

8. Discussion

The above results show that the frequency of cold waves in Guangdong has not changed significantly over the past few hundred years, averaging about four times per year. Although the trend is not apparent, a slight decrease can still be seen. In general, under the five SSP scenarios, the frequency of cold waves in Guangdong will show a decreasing trend in 2015 and 2100, but with different magnitudes. Under the SSP 1-1.9 scenario, the cold wave frequency will stabilize around three and then gradually increase in the mid and late 2000s. However, there is a clear downward trend at the beginning. In the SSP 5-8.5 scenario, the frequency of cold waves would even halve at the end.

Fu and Ding (2021) found that over the course of the last six decades, there has been a general declining trend in the frequency of occurrences in China that are classified as regionally strong cold [3]. On the other hand, it appears from the findings presented thus far that the occurrence of cold waves in Guangdong did not dramatically lessen throughout the course of the 20th century. This suggests that the occurrence of cold waves in China may be drastically different throughout the country's regions. According to the findings of a study, the number of cold waves that have occurred in the most recent 30 years (1981-2010), at the majority of Guangdong stations, has been fewer than the number of cold waves that have occurred in the previous 30 years (1971-2000) [4]. This discovery is in line with the results that came before it, despite the fact that there is a little downward tendency.

Overall, the frequency of cold waves in Guangdong will show a decreasing trend in 2015-2100 under the five SSP scenarios. This result is consistent with that of North China regarding the occurrence of future cold waves [10]. Park et al. (2011) stated that throughout the middle and latter parts of the 21st century, the number of cold waves that affected East Asia did not significantly change when compared to the late 20th century [11]. This is in contrast to simulations from the late 20th

century. On the other hand, Yang et al. 2021 predicted that the occurrence of total cold waves will become significantly less common in the 21st century [12].

Although different studies showed different results, this may be because they used different definitions of cold waves. In addition, other regions may offer different trends in the frequency of cold waves in the future.

From the comparison of time series model prediction effects of moving average method, Holt linear trend method, Holt Winter method, seasonal autoregressive analysis (SARIMA) method, and long and short-term memory models among deep learning, the seasonal autoregressive analysis (SARIMA) was found to be more effective in the five SSPs. The five SSP scenarios have the most accurate and realistic predictions of the frequency of cold wave occurrence.

9. Conclusion

The study uses daily minimum temperature data from the CanESM5 model for the ensemble r1i1p1f1 under five SSP scenarios, SSP 1-1.9, SSP 3-7.0, SSP 4-3.4, SSP 4-6.0, and SSP 5-8.5, To compute the frequency of cold waves in Guangdong from 1900 to 2100, to forecast the future trend of cold wave frequency in Guangdong, and to compare it to the past, comparisons are done. The conclusions are summarized as follows: From 1900 to 2014, the cold wave frequency in Guangdong was generally stable at level 4, However, a modest decline in cold wave frequency can still be observed, especially in the last decade. According to the SSP 1-1.9 scenario, the expected number of times cold waves will show a decreasing trend at the beginning but will remain and eventually increase in the mid and late 20th centuries. The cold wave frequencies in the SSP 3-7.0, SSP 4-3.4, SSP 4-6.0, and SSP 5-8.5 scenarios will all decrease. They will even be halved in the SSP5-8.5 scenario. The trend of cold wave frequency changes in different regions of China in the past is different, and the decreasing trend is more evident in China. Different definitions of the cold wave will affect the prediction results of the frequency of future cold waves. The comparison of the effects of different models shows that the seasonal difference autoregressive sliding average model has the best prediction of the frequency of future cold wave occurrence under the 4 scenarios of SSP except for the first scenario. Choose only one grid scenario to represent the whole of Guangdong. Since this method does not accurately portray the overall situation in Guangdong, a more accurate definition of the cold wave should be used to predict the change of future cold wave frequency in different regions of Guangdong.

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