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Analysis of the dynamic impacts of global climate change on ocean ecosystems

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Abstract:

This essay will discover the application of two time series analysis methods, which will focus on the Auto-regressive Moving Average (ARMA) and Vector Auto-regression (VAR), and explore the impact of global climate change on marine ecosystems. The first ARMA model is combined with Auto-regressive (AR) and Moving Average (MA) components, which is able to capture the influence of historical data and previous forecast errors on current observation. Besides, VAR model can contribute to explore a series of variables, such as the temperature of see, and species amount. The results show that ARMA model effectively captures long-term impacts and short-term deviations. Meanwhile, this essay give recommendation for future research, and how to better capture the complicated climate change.

Keywords: ARMA;VAR;climate change;marine ecosystem.

1. Introduction

The global climate change has become one of the most serious environment issues in the 21st century, and it has already deeply impact on the global ecosystem [5]. Global warming is a worldwide problem which can data back to the Industrial Revolution, when there was a massive amount of emissions of greenhouse gases, and it made a great impact on atmosphere condition [7]. Nowadays, the climate change has a series of impacts on ocean ecosystems, including but not limited to ocean current change, seawater temperatures, the popularity of ocean animals, and the diversity of ocean species [6]. For example, the temperature of seawater increases significantly with global warming, and the habitat of marine organisms is disrupted [1]. Marine animals will migrate to areas with lower temperatures such as the North and South Poles [2]. Plants, on the other hand, apparently do not have this ability, so a global coral bleaching event occurs. In addition, rising sea levels are threatening the human environment. There are more areas of the globe where the elevation is equal to the sea level [3]. The melting of glaciers leads to sea level rise, which poses a serious threat to human life in coastal cities [4].

1.1 Background of the model

People invent many different statistical models to analyze time series data, which contributes to the exploration of the impacts brought by climate change on the complexity of marine ecosystem. The Auto-regressive Moving Average model (ARMA) combines the Auto-regressive model (AR) and the Moving Average model (MA) [15]. As for ARMA model, the

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AR model focuses on the impact brought by historical data, while the MA model focuses on the random fluctuations [16]. Therefore, ARMA model can use the past data and the forecast error to predict current observed value, which is contributes to effective analysis of time series, but there is still existing deficiency for ARMA to capturing the complex interaction among multiple variables [17]. The general-version of ARMA was proposed in 1951. Peter Whittle [14] investigated the hypothesis testing in time series, and introduced the model. After about 20 years, George E. P. Box and Gwilym Jenkins [13] published a monograph that made ARMA being popularized. Recently, ARMA has been one of the most critical statistical/mathematical tools, which is applied to both theorical and applicable fields [18, 19].

People invent Vector auto-regressive (VAR) models to overcome the limitations that has been mentioned above. VAR model expands the concept of AR model, and, thus, it can be used to deal with the complex interactions among various variables, such as the change of ocean current, the temperature of seawater, and the diversity of ocean species [8]. As an outcome, The VAR model can sufficiently reflect that how those variables affect each other, which contributes to help discovering the internal relationship of marine ecosystems [9]. However, there still are many existing challenges for VAR model, though it already has many advantages, especially when face the problem of analyze the nonlinear relationships and abrupt changes.

Four decades ago, VAR framework was considered by Christopher Sim, which provided a great-promise statistical technology [12]. Based on the flexible properties of VAR, certain utilizations were found. For univariate time series, Engle and Manganelli and White et al. applied the idea of quantile analysis to VAR [11]. Applications such as these are numerous, reflecting not only the significance of the underlying model, but also that model exploration should take more factors into account in practice [10]. By reviewing the classical models, new models that are more generalizable may be proposed.

1.2 Research purpose and content

This paper mainly selects and refers to previous studies related to VAR models and ARMA models to systematically review and analyze climate change and marine ecosystems. For some extended models, this paper tries to explore their application value in climate and ocean. This paper explored the application of ARMA and VAR models in studying the impacts of climate change on Marine ecosystems, which aims to improve our understanding of how climate change affects Marine species and ecosystems. The study will employ ARMA to assess the effects of historical ocean temperatures and short-term climate shocks, while VAR will be used to study the interactions between multiple ecosystem variables. The study will also highlight the limitations of these models and suggest areas for future research.

1.3 Research results and outline

The results show that the ARMA model can effectively capture the long-term effects of ocean temperature change and the short-term deviations caused by climate shocks. Instead, the VAR model reveals the interactions between variables, such as how changes in sea temperature affect ocean currents and species density. In addition, VAR and ARMA models, besides their value for direct studies of climate and ocean, have important roles to play in nature and human society. Therefore, this paper proposes to apply such time series models to analyze more types of data, such as ship transportation, to form an indirect study of climate and ocean.

This paper is structured as follows: a review of the ARMA and VAR models, an analysis of their applications to climate change and Marine ecosystems, a discussion of the results, limitations of the models, and recommendations for future research.

2. Method

The Autoregressive Moving Average Model (ARMA) model is a widely used time series analysis method that combines two components, specifically, the Autoregressive (AR) and the Moving Average (MA) models.

2.1 Autoregressive Model

Let $t, p \in Z_+$ be two positive integers, where $t \geqslant p$, and Z_+ denotes the set of all positive integers. The AR component models use a number of p past observations to predict the current or the future observations. Formally, given a time point t, the explicit model is

$$X_t = c + \varphi_1 X_{t-1} + \varphi_2 X_{t-2} + \cdots + \varphi_p X_{t-p} + \varepsilon_t$$

where:

X_j, $j = t-p, \ldots, t-1, t$, are the interested values of the time series at time j. φ_i, $i = 1, \ldots, p$, are the model parameters, which represent that the lag effect of the time series from the previous p times period. The lag effect refers to the delay or lag in the impact of one event or variable on another. In time series models, it describes how past value affect the current value.

$c \in R$ is a constant term, where we denote the set of all real-finite numbers by R. ϵ_t is the white noise error term, indicating random fluctuations that can not explained by the model. The distribution of ϵ_t is usually considered as $N(0,1)$, which indicates that the noise error term might follow a normal distribution with zero mean and one standard error. This consideration is realistic in the vast majority of cases, due to the fact that the effect of the noise term on the values taken from the time series can be positive or negative. On the other hand, the value of the noise term is unpredictable, is a random variable, and is likely to be varied for different moments.

The role of AR in study is that it helps learn about the impact of global climate change on marine ecosystems, and the AR component helps in modeling and understanding how marine ecosystem variables, such as sea temperature, and species density, are influenced by their historical states. For instance, the density of whale populations may be affected by the densities from previous periods.

2.2 Moving Average Model

Besides, The MA component is a formula which models the current value as the past prediction errors.

$$X_t = \mu + \theta_1\epsilon_{t-1} + \theta_2\epsilon_{t-2} \cdots + \theta_q\epsilon_{t-q} + e_t$$

θ_j is the model parameters, which represents the lag effect of each forecast error, and shows the observed values. In research, MA can be used to analyze the impact of climate change on marine ecosystems, and MA components can be used to simulate and analyze the impact brought by random climate shocks on ecosystem variables, such as some extreme weather conditions, include but not limited to tsunami, volcanic eruptions, and typhoons. For example, the storm might have a short-term and direct impact on marine ecosystems.

2.3 ARMA Application to Climate Change and Marine Ecosystems

The ARMA is a model which combines AR and MA, and the ARMA take both past observation and forecast errors into consideration.

It can be represented as:

$$X_t = C + \varphi_1 X_{t-1} + \varphi_2 X_{t-2} + \cdots + \varphi_p X_{t-p} + \theta_1\epsilon_{t-1} + \theta_2\epsilon_{t-2} \cdots + \theta_q\epsilon_{t-q} + \varepsilon_t$$

In the research of the impact that brought by climate change on marine ecosystem. AMRA analyze how the ocean temperature, species density, and random climate shocks impact marine ecosystem variables in the future. For example, AR can be used to predict the long-term effects that brought by ocean temperatures on marine species population, and MA is helpful to identify and explain the short-term biases caused by climate events.

2.4 Vector Autoregression Model

The Vector Autoregression (VAR) model deal with the multiple related time series by extending the concept of AR. It captures the linear relationship between multiple variables, which is contributes to analyze the complex interactions among multiple time series data.

The formula of VAR is:

$$y_t = C + A_1 y_{t-1} + A_2 y_{t-2} + \cdots + A_p y_{t-p} + u_t$$

Where y_t is a vector of time series variables at time, C is a constant term, A_p are matrices of parameters that can capture the effects brought by all the past values of variables on current values, and u_t is a vector of error term.

2.5 VAR Application to Climate Change and Marine Ecosystems

The VAR model allows to analyze multiple variables at the same time, such as ocean temperature, ocean currents, and species diversity. This model is useful to explain how the interactions among variables respond to climate change. For example, it can reveal how the changes of ocean temperature impact ocean currents, which will impact the nutrient distribution and the marine species diversity.

3. Results and Discussion

3.1 Results of ARMA Model

From the data of marine ecosystem and climate analyzed by ARMA model, it is significant that AR remarkably capture the impact brought by historical temperature on current temperature.This model shows a significant lag effect, which means that the historical ocean temperatures is still continuous impact current temperatures. The MA component identifies short-term deviations that relevant to climate shocks, such as extreme weather events. For example, this model detexted significant volcanic eruptions will lead to abnormal phenomena in marine species densities, which means the short-term impact on ecosystem. In addition, ARMA can be combined with principal component analysis methods, such as the ARMA-PCA model, which can predict future population densities by using past time series of marine organisms. ARMA modeling also protects the global environment in an indirect way, for example, ARMA models can be used to predict the spread of pests; protect vegetation, animals and humans, and thus indirectly influence the climate [20].

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3.2 Results of VAR Model

The VAR model provided a comprehensive view of the interactions among multiple variables. It represented that changes of sea temperature had a direct and significant effect on ocean currents and species diversity. Additionally, this model revealed that the nutrient distribution is influenced by ocean currents, and, thus, affected the marine species diversity. The VAR model strengthened on the relationship among variables, which shows that the change of one variable often will lead to a cascading effect to others. In addition, the VAR model allows researchers to analyze things related to marine life. For example, giving effective measures efficiently to provide protect for the living environment of ocean species by analyzing the spreading phenomenon of oil spills.

4. Discussion

There are several factors causes the differences between ARMA and VAR. Firstly, the reliability of the short-term prediction result will be decreased due to that the ARMA model is sensitive to data noise. However, the multiple variable method provide a more comprehensive variable interaction view. Secondly, ARMA models might ignore the complex interaction among multiple variable since the ARMA model focuses on single variable, while VAR model can provide a more comprehensive analysis of the interact relationship. Thirdly, the ARMA might be impacted by hysteresis effect and error term, while the VAR model can well reflect the relationship among multiple variables.Lastly, the ARMA-PCA model that proposed in this article can not only be used to predict the combination of ocean species sample, but also can be used to predict the climate change. Additionally, it is a new application direction of ARMA-PCA model, because climate change and ocean species is highly related.

4.1 Limitation

Both ARMA model and VAR model have been simplified, which means that it is difficult for those two models to capture the complex impact brought by climate change on marine ecosystem. For example, the ARMA model might miss the interaction among multiple variables, while VAR model may unable to analyze the nonlinear effects and external factors.

The limitation of ARMA is that ARMA requires data must be stable, which always needs smoothing time series. this pre-processing might sometimes oversimplify the data, and, thus, potentially leading to the loss of important temporal dynamics [21]. In practice, this means that subtle but significant trends or variations might be missed, affecting the model's accuracy and relevance to real-world scenarios.

The limitation of VAR model is that it is difficult for VAR model to deal with the non-linear interaction, VAR model is good at capturing linear relationship among multiple time series. This advantage is significant when researching the complex processes of climate change, such as the sudden change of ocean events and ENSO events. All in all, both VAR model and the linear models that are similar with VAR might lack contentious performance, because they are unable to fully capture nonlinear dynamics and abrupt changes [22]. Therefore, it might cause that the conservative prediction cannot reflect the real extent of climate impact.

5. Conclusion

In conclusion, it is quite valuable for studying the impact brought by goalball climate change on marine ecosystem by learning about the application of ARMA model and VAR model. The ARMA model can be considered as a clear way to understand the impact of historical data and short-term climate shocks, while VAR model enhance our understanding of the complex interaction among multiple variables. Although both of this two models have different advantages, there still are limitation for each of them, and, thus, influence the accuracy and comprehensiveness of models. For example, ARMA is too sensitive to analyze data noise, and VAR needs to enhance its way of analyzing time series, because it is still difficult for it to analyze the interaction of nonlinear. In the future, the research need to pay more attentions on integrating nonlinear models and exploring more external factors, which contributes to comprehensively capture the impact of ocean brought by climate changes.

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