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Empirical orthogonal functions (EOF) analysis of spatial patterns of dominant variability in the Indian Ocean

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ABSTRACT

The Indian Ocean plays a crucial role in the global climate system, particularly in influencing the seasons in Indonesia. Sea surface temperature (SST) variability in the Indian Ocean affects rainfall patterns, extreme events, such as droughts and floods, in Indonesia. This study analyzes SST variability during the dry season (June – July – August, JJA) and rainy season (December – January – February, DJF) using satellite and reanalysis data from 1981 to 2023 with the empirical orthogonal function (EOF) method. The analysis shows that the dominant SST variability pattern during JJA is related to the Indian Ocean dipole (IOD), which influences rainfall and temperature patterns in Indonesia. In DJF, SST variability is more associated with the Asian-Australian monsoon, affecting rainfall patterns and the potential for floods. This research enhances the understanding of climate dynamics in the Indian Ocean and its impact on Indonesia, and it can be used to predict extreme climate events associated with SST variability.

Keywords: EOF; Indian Ocean; IOD; sea surface temperature (SST)

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INTRODUCTION

The Indian Ocean is the third largest ocean in the world and plays an important role in the global climate system. Sea surface temperature (SST) in the Indian Ocean shows significant variability, influenced by various factors such as monsoon winds, ocean currents, and atmosphere-ocean interactions [1]. Climate phenomena such as the Indian Ocean dipole (IOD) and el niño-southern oscillation (ENSO) also contribute to SST variability in this region. SST variability in the Indian Ocean has a broad impact on weather and climate conditions in various parts of the world, including Indonesia.

Indonesia, as an archipelagic country located between the Indian Ocean and the Pacific Ocean, is very vulnerable to the impacts of SST variability in the Indian Ocean. Changes in SST can affect monsoon wind patterns, rainfall intensity and distribution, and extreme events such as floods and droughts in Indonesia [2]. Therefore, a deep understanding of SST variability in the Indian Ocean, especially during periods that affect the seasons in Indonesia, is very important to improve climate prediction and disaster mitigation capabilities.

This study aims to analyze SST variability in the Indian Ocean with a focus on the dry season (June – July – August, JJA) and rainy season (December – January – February, DJF) using data from 1981 to 2023. This period was chosen because it represents the contrast of climate conditions in Indonesia which are influenced by the monsoon. In the month of JJA, the dry eastern monsoon dominates causing a decrease in rainfall in Indonesia. Conversely, the western monsoon brings moist air from the Indian Ocean which causes an increase in rainfall in Indonesia in the month of DJF.

The empirical orthogonal function (EOF) method will be used to identify the dominant patterns of SST variability in that month. The EOF method is effective in reducing data dimensions and revealing the dominant spatial patterns of SST variability [3]. As shown by Dipo in 2011, the EOF method can be used to analyze the characteristics of physical oceanography in the Indian Ocean, including SST variability [4]. It also shows that SST variability in the Indian Ocean, especially IOD, can be influenced by global warming [5].

By identifying the dominant patterns of SST variability in the Indian Ocean in DJF and JJA, this study is expected to improve understanding of climate dynamics in the Indian Ocean and its impacts on Indonesia, as well as to develop adaptation and mitigation strategies against climate change.

RESEARCH METHODS

Research Method This study aims to analyze the variability of SST in the Indian Ocean with a focus on the rainy season (DJF) and dry season (JJA) in Indonesia using the EOF method. This method was chosen because of its ability to reduce the dimensions of complex data and reveal the dominant spatial patterns of SST variability, as has been proven in various studies [1, 3, 4].

The data used in this study are monthly SST data from 1981 to 2023 obtained from the National Oceanic and Atmospheric Administration (NOAA). The SST data used has a spatial resolution of 1º × 1º.

Data Processing

- Data selection: Monthly SST data will be selected and grouped based on the DJF and JJA seasons.
- Seasonal average calculation: Monthly SST data will be averaged for each DJF and JJA season period each year.

Data Analysis

EOF Analysis

- The EOF method will be applied to the seasonal mean SST data (DJF and JJA) to identify the dominant patterns of SST variability in the Indian Ocean.
- EOF will generate a series of orthogonal modes, where each mode represents an independent pattern of variability.
- The eigenvalues correlated with each EOF mode will be calculated to determine how much the mode contributes to the total variance of the data.
- The EOF modes with the largest eigenvalues will be further analyzed, as these modes are the dominant modes that explain most of the SST variability.

Interpretation of Spatial Patterns

- The spatial patterns of the dominant EOF modes will be visualized in the form of maps to identify areas in the Indian Ocean that have similar SST variability.
- These spatial patterns will be interpreted to understand the characteristics of SST variability in the Indian Ocean during the DJF and JJA periods.

Data processing and EOF analysis will be carried out using Python software using the Pycharm application with appropriate libraries for data analysis and visualization.

RESULTS AND DISCUSSION

EOF in statistics is a multivariate analysis technique used to identify dominant patterns in a dataset spatially and temporally. The EOF method determines dominant patterns in three stages, namely;

- Covariance Matrix: This matrix shows the correlation between SST anomalies at each pair of grid locations.
- Eigenvalue Decomposition: The covariance matrix is decomposed into eigenvalues and eigenvectors. Eigenvalues represent variance by each EOF mode, while eigenvectors represent spatial patterns
- Dominant Mode Selection: Then the EOF modes will be sorted based on the eigenvalue value. The largest eigenvalue explains the largest variance in the data and is considered the dominant mode.

So that finally this EOF analysis will produce a percentage of dominant variants, spatially dominant patterns and temporally dominant patterns.

June – July – August (JJA)

Dominant Pattern I

This dominant pattern I EOF shows a dominant variant percentage of 45.8% with an average increase in SST in the western Indian Ocean. This is indicated by the solid red color pattern in Figure 1. This pattern indicates a positive IOD which results in an increase in SST in the western Indian Ocean.

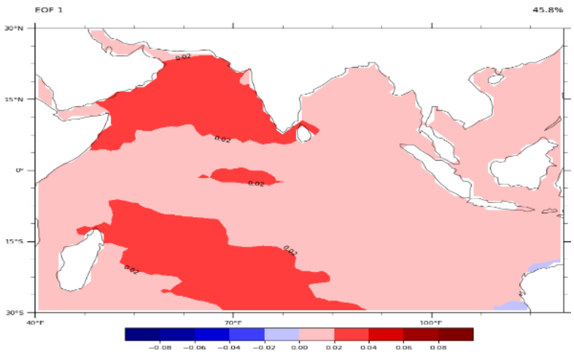

Figure 1. Spatial dominance pattern I of the Indian Ocean EOF in JJA (1981 – 2023).

Dominant Pattern II

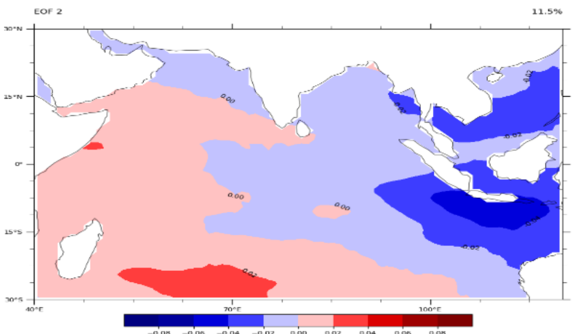

Figure 2. Spatial dominance pattern II of the Indian Ocean EOF in JJA (1981 – 2023).

This dominant pattern II EOF has a dominant variant percentage of 11.5%. There is a high decrease in SST in the eastern Indian Ocean and the southern parts of Arabia and India. This pattern is more complex than the previous pattern because it can be caused by various factors. These factors can be due to the presence of the Asian moonsun, ocean currents or even the presence of equatorial currents.

Dominance Pattern III

This pattern shows a percentage of variance of 7.9% with a significant decrease in SST in the central area of the Indian Ocean, while around it there is a significant increase in SST. This pattern can be caused by local atmospheric circulation or even the influence of the Pacific Ocean, for example the influence of ENSO.

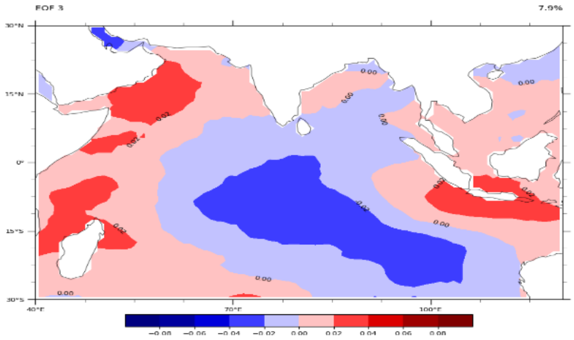

Figure 3. Spatial dominance pattern III of the Indian Ocean EOF in JJA (1981 – 2023).

December – January – February (DJF)

Dominance Pattern I

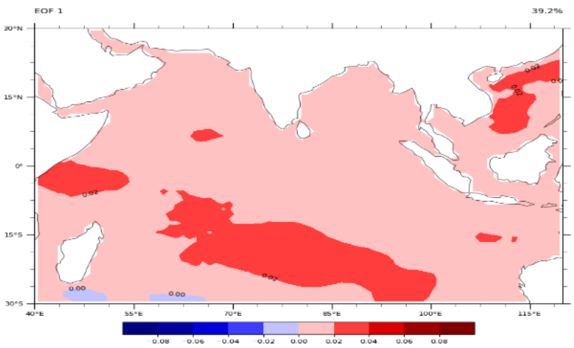

Figure 4. Spatial dominance pattern I of the Indian Ocean EOF in DJF (1981 – 2023).

Figure 4 shows a dominant percentage of variance of 39.2% with a significant and even increase in SST in the central Indian Ocean. This pattern likely indicates the influence of the Asian-Australian Monsoon. During the DJF season, this monsoon is in its active phase, which is characterized by strong westerly winds in the Indian Ocean. Another possibility is the influence of the sun's position, because in the DJF month the sun is in the southern hemisphere (BBS).

Dominance Pattern II

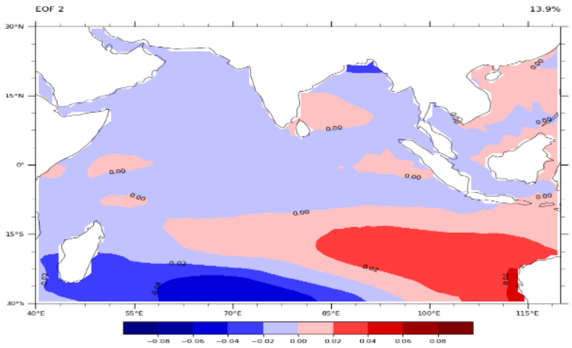

Figure 5. Spatial dominance pattern II of the Indian Ocean EOF in DJF (1981 – 2023).

Figure 5 shows a dominant percentage of 13.9% and a more localized SST distribution. This pattern shows variations in the intensity and pattern of the monsoon winds from year to year. Although the Asia-Australia monsoon is in its active phase, these variations can affect ocean circulation and SST distribution. Other factors that may play a role are local atmospheric interactions and the influence of other climate phenomena such as IOD and ENSO.

Dominance Pattern III

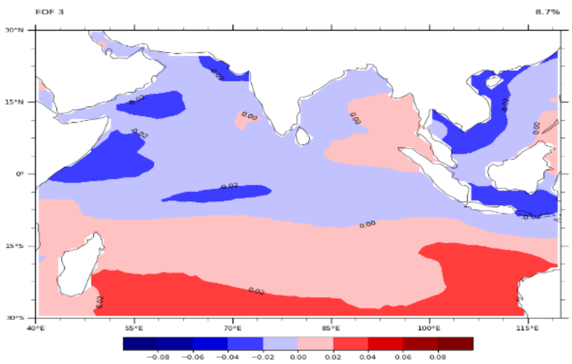

Figure 6. Spatial dominance pattern III of the Indian Ocean EOF in DJF (1981 – 2023).

Figure 6, EOF 3 shows a dominant percentage of 8.7%. It is seen that the dominant decrease in SST occurs in the northern part of the ocean while there is a significant increase in SST evenly in the southern part of the Indian Ocean. This pattern is likely influenced by the Madden-Julian Oscillation (MJO), which can modulate rainfall and wind patterns in the Indian Ocean and have an impact on SST.

CONCLUSION

EOF analysis of SST in the Indian Ocean produces dominant patterns of variability in both JJA and DJF months. In JJA, the IOD pattern is more dominant, while in DJF the Asia-Australia monsoon pattern is more prominent. In addition to these dominant patterns, there are also other more complex and localized patterns of variability. This is influenced by various factors such as variations in the west and east monsoons, ocean currents, atmospheric interactions, and large-scale climate phenomena such as ENSO and MJO.

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