Analysis of climate indicator association with hotspots in Indonesia using heterogeneous correlation map

M Dafri¹, S Nurdiati¹, A Sopaheluwakan², P Septiawan¹

¹Mathematics Department, Faculty of Mathematics and Natural Science, IPB University, Bogor 16680, Indonesia
²Center of Research and Development, Agency for Meteorology Climatology and Geophysics, Jakarta 10720, Indonesia

Email: dafri_57@apps.ipb.ac.id

Abstract. In several regions, land and forest fires of Indonesia occurred almost annually during the drought season. The severity of Indonesia’s drought season is mainly influenced by the Australian Monsoon, local cloud formation controlled by Sea Surface Temperature (SST) around Indonesia. Moreover, it affects the severity of land and forest fires itself indirectly. This research aims to examine the association of the Australian Monsoon and local SST with land and forest fires in Indonesia. This research uses the Australian Monsoon Index (AUSMI) as an indicator for the Australian Monsoon and SST in the Karimata Strait and the Java Sea as indicators of local SST. An indicator of land and forest fires that will be used is the number of hotspots. A heterogeneous Correlation Map (HCM) is used to describe hotspots associated with AUSMI and local SST. The analysis shows that the east wind pattern of AUSMI associated with hotspots in Indonesia, especially in years when zonal winds enter an upward phase more slowly. Karimata Strait’s SST is associate with hotspots in the coastal part of Riau. Meanwhile, Java Sea’s SST is associate with hotspots in Lampung, South Sumatra, Jambi, and Kalimantan.

1. Introduction

Land and forest fires in Indonesia have long been a concern of the Indonesian and world governments. That’s due to the impact that can causes problems on the environment, economy, and public health [15][7][17]. Among the major fires in Indonesia occurred in 1997 and 2015. In 1997, an estimated 13 million Ha of land and forest were burned and emitted nearly the equivalent of 15% of global carbon emissions from fossil fuels [6]. Meanwhile, land and forest fires in 2015 in Indonesia burned more than 2.6 million hectares of forest and non-forest land. Most of this land contains biodiversity and endangered species such as orangutans, tigers, rhinos, and elephants [20]. Economic losses from land and forest fires in Indonesia are estimated to exceed the US $4.5 billion in 1997–1998[3] and the US $16 billion in 2015 [20]. Recent research shows that land and forest fires occur almost every year in Indonesia, especially during the dry season [16].

One of the most influencing climate variability in tropical and subtropical areas is the Asian-Australian Monsoon system [8]. For example, in the Asian-Australian monsoon system, dry air from the continent with winter flows across the equator towards the earth’s continent, with summer taking moisture from the warm oceans that it passes through and forming rain clouds and will continue to carry it to the summer continent. When the Australian continent is experiencing winter, the Australian mainland will become a center of high pressure. As a result of the pressure, there was a movement of monsoon winds from the Australian continent through to the Indian Ocean from the southwest to the Asian continent which experienced summer. However, when passing through the oceans, the winds originating from Australia only pass through a narrow part of the Indian Ocean, so that little water is carried, so that when the wind blows from the continent of Australia to the Asian continent, in Indonesia, there will be a dry season. This type of monsoon wind is known as Australian Monsoon [10]. Considering that land and forest fires in Indonesia occur almost every year, especially during the dry
season, it will be exciting to know about the association of land and forest fires in Indonesia with the Australian Monsoon. Also, Indonesia is an archipelagic country and has a vast sea, so the climate in Indonesia will not be separated from the influence of SST in Indonesia itself [14][11][18]. Climate is influenced by the topography of an area and fluctuations in the ocean atmosphere [5]. Ocean atmosphere fluctuations can change according to Sea Surface Temperature (SST) around the region [2][19]. In addition to the Australian Monsoon, this research also try to analyze the association of SST in Indonesia with forest fires in Indonesia.

In this study, the Australian monsoon index (AUSMI) is used as an indicator for the Australian Monsoon. Average of the Karimata Strait’s SST and the Java Sea’s SST used as an indicator for local SST. Meanwhile, the number of hotspots uses for land and forest fire indicators in Indonesia. Singular Value Decomposition (SVD) analysis uses to determine the association of AUSMI, Karimata Strait’s SST, and Java Sea’s SST with hotspots in Indonesia. The SVD analysis results show using a Heterogeneous Correlation Map (HCM) to describe the spatial association of hotspots in Indonesia with climate indicators for each grid. Furthermore, the results of the SVD will also be analyzed temporally.

2. Methods

2.1. SVD analysis

Analysis of Singular Value Decomposition (SVD) generally was used to identify independent spatial and temporal patterns of data, where SVD analysis explains the fraction of the covariance of data [12]. This research uses the zonal wind dataset from the National Centre for Environmental Prediction (NCEP) for AUSMI and Optimum Interpolation Sea Surface Temperature (OISST) from the National Oceanic and Atmospheric Administration (NOAA) for Karimata strait’s SST and Java sea’s SST. Hotspot dataset in Indonesia in the area of 6°N-11°S, 95°E-141°E that has 0.25° × 0.25° degree with time series monthly from 2001 to 2019 obtained from the Agency for Meteorology Climatology and Geophysics of Indonesia. SVD analysis was applied on the cross-covariance matrix constructed from the matrix of hotspot data (P) and the matrix of climate data (S). The cross-covariance is obtained from the product of P and ST as follows.

\[ C = P S^T \]  \hspace{1cm} (1)

Applying the SVD, C’s temporal average was filtered out to facilitate a more straightforward interpretation of the results in terms of their anomalies. SVD reduction on the cross-covariance matrix C will result in

\[ C = U \Sigma V^T \]  \hspace{1cm} (2)

\( U \) is a singular vector of hotspot matrix, and \( V \) is a singular vector of climate indicators. It \( \Sigma \) is a diagonal matrix that contains singular values of cross-covariance matrix \( C \) [12]. Spatial patterns and temporal patterns can be obtained from the modes of singular vectors \( U \) and \( V \). This research used only two modes to be analyzed and considered sufficient to describe the hotspot variability in Indonesia [12].

2.2. Temporal Analysis

The temporal analysis was performed on the expansion coefficients of each data matrix. The expansion coefficient for hotspots in Indonesia was obtained from the matrix \( U^T \) and matrix \( P \) product. The expansion coefficient of climate indicators was obtained from the product matrix \( V^T \) and matrix \( S \). In detail, these are given as follows.

\[ E_1 = U^T P \]  \hspace{1cm} (3)
\[ E_2 = V^T S \]  \hspace{1cm} (4)

\( E_1 \) is a temporal pattern of the hotspot matrix for each mode, and \( E_2 \) is a temporal pattern of climate indicators for each mode [1].
2.3. Heterogeneous Correlation Map (HCM)
The spatial analysis used the Heterogeneous Correlation Map (HCM) to describe the correlation of hotspots in Indonesia with climate indicators' variances values. HCM hotspots in Indonesia were obtained from the Pearson correlation expansion coefficient of climate indicators variances with hotspots matrix in Indonesia \( r(E_2, P) \)[1]. Ranges of Pearson correlation value can be seen in Table 1 below.

| \( r \) (Value) | Strength of correlation          |
|-----------------|----------------------------------|
| 0               | No correlation                   |
| 0 - 0.25        | Very weak correlation            |
| 0.25 - 0.5      | Sufficient correlation           |
| 0.5 - 0.75      | Strong correlation               |
| 0.75 - 0.99     | Very strong correlation          |
| 1               | Perfect correlation              |

2.4. Variances of data
The total variance is an amount given by the diagonal element of \( \sum \). Because of the trace's invariance property, the total variance is also provided by the sum of the squared singular values. Dividing them by the trace, we can get the percentage contribution \( \mu_i \) and \( \theta_i \) of each mode \( \sigma_i \) [12].

\[
\mu_i = \frac{\sigma_i^2}{\sum_{i=1}^{n} \sigma_i^2}
\]

3. Result and Discussion
3.1. Data Extraction
AUSMI was obtained from the average zonal wind anomaly in the AUSMI region with an altitude 850 hPa. The data was used is monthly data with grid resolution 2.5° × 2.5° and time 2001 up to 2019. The matrix size for each year is 144 × 73 × 228. However, the matrix was cuted in the AUSMI region and produced a matrix in 4 × 8 × 228 size, and converted it into two-dimensional matrix with the size 32 × 228. Figure 1 shows an example of the zonal wind spatial pattern in the AUSMI region in July 2001.

![Figure 1. Zonal wind plot at 850 hPa altitude in July 2001.](image)

This research also analysis the impact of local SST on land and forest fires in Indonesia. Sourced data is the same as used in ENSO and IOD, namely global SST data that is truncated on the Indonesian SST area. The result of the truncated process is a matrix with the size 196 × 69 × 228. Figure 2 shows an Indonesian SST map in July 2001.
Because of the various characteristics among of Indonesian local SST, it is necessary to identify the specific area representing SST characteristics and associated hotspots correctly. Indonesian regions that produced hotspots correlated with annual forest fire are Kalimantan, South Sumatra, and Riau [13]. Therefore, Karimata Strait and the Java Sea, close to those three areas, are chosen as local climate indicators. The Karimata Strait area's truncate process produces a matrix with the size $475 \times 228$, whereas the Java Sea produces a matrix with the size $17 \times 47 \times 228$. In the analysis, both of those data are transformed into two-dimensional data resulting matrix in size $475 \times 228$ for Karimata strait’s and a matrix in size $799 \times 228$ for Java sea’s. The spatial maps of the Karimata strait’s and Java sea’s SST in July 2001 are shown in Figures 3 and 4.

As mentioned before, the climate indicators were analyzed together with the land and forest fire to get the common pattern between them. This research uses the number of hotspots as the land and forest fires indicator. The hotspots data was used is monthly data with grid resolution was $0.25^\circ \times 0.25^\circ$ from 2001 up to 2019. The matrix size for hotspot data was $69 \times 196 \times 228$. Similar to climate indicators, the hotspot data will be converted, and it becomes a matrix with the size $13524 \times 228$. Figure 5 shows the Indonesian hotspots map in July 2001. Analysis in this research utilizes several time lags between hotspot and climate indicators, named lag-0(without lag), lag-1, lag-2, and lag-3. The time lag was used to replicated natural behaviors where the hotspot occurs in the middle of the dry season caused by several climate indicators that happened even before the dry season starts. The number in lag represents the
difference in the month between both data. For example, lag-1 means that the hotspot data's time series is one month ahead of the climate data.

The SVD analysis of the hotspot and both local climate indicators and AUSMI is resulting in 228 modes. However, only two modes are used for further analysis because the variance explained accumulation for each climate indicator's first two modes is already more than 95%. Therefore, the first two modes’ analysis is sufficient to describe the variability of hotspots in Indonesia with all used climate indicators.

3.2. SVD analysis of the hotspots in Indonesia and AUSMI.

Figure 6 shows the SVD analysis results to the number of hotspots in Indonesia and AUSMI with lag-0. The variance explained for the first mode is 96.56%.

Figure 6 and 7 shows first mode’s spatial and temporal pattern from the analysis of hotspots and AUSMI. The spatial pattern of AUSMI in Figure 6 shows that the first mode represents the east wind pattern which causes a dry season in Indonesia. Furthermore, the seasonal cycle of the AUSMI in Figure 7 shows the positive value of the zonal winds that occurred in the early year, whereas the negative value occurred in mid to end of the year. However, the hotspots' temporal pattern shows that the number of hotspots rises from the middle to the end of the year. Therefore, the east wind pattern in the first mode is related to the hotspot regions, which negatively correlate with the AUSMI. Some of the areas that show the strongest correlation between hotspot and AUSMI are South Sumatra, Jambi, and Riau, which shows by the hotspot’s spatial pattern in Figure 6. Those three regions have a negative correlation in the range of 0.25 up to 0.5 with a zonal wind pattern that blowing eastward.

The variability of the zonal wind cycle pattern did not show clearly in Figure 7. It is hard to see the difference value among the zonal wind that occurred in each year. However, the hotspots' temporal pattern shows a high number of hotspots occurred when the zonal winds entered an upward phase more slowly than in other years. This result also can be seen from the bubble chart below.
Figure 8. Bubble chart of the length of the dry season, last month of the dry season and number of hotspots

Figure 8 shows the dry season's character in the first mode, which is influenced by zonal winds movement and identified using the AUSMI indicator. The length of dry season and last month of the dry season was identified by using the positive value from temporal pattern of AUSMI. The trend line represents the dry season that starts in April. The area below the trend line describes the late dry season, which begins in May, whereas the area above the trend line describes the early dry season, which starts in March. Figure 8 shows that the number of hotspots in the three regions already mentioned before is greatly influenced by the dry season's length and the final month of the dry season in the particular year. The upward phase of zonal winds is correlated with the end of the dry season in the particular regions. Therefore, when the dry season's length increases or the dry season ends lately, the upward phase of zonal winds will be delayed.

Figure 9. Second mode HCM of AUSMI and hotspot in Indonesia
The second mode of AUSMI and hotspots is 3.11%. The spatial pattern of AUSMI in the second mode shows a mix between eastward and westward wind. The temporal pattern in Figure 10 shows that the high number of hotspots occurred when the AUSMI has a positive value. Therefore, the second mode is related to the regions that have a positive correlation. The spatial hotspot pattern in Figure 9 shows that the positive value of correlation occurred in Riau province in the range of 0 to 0.25. The difference between the first mode, the second mode represents a hotspot in the early year, as shown in Figure 10. Figure 10 shows that the pattern is related to the high number of hotspots in the early year of 2005 and 2014. However, the AUSMI second temporal pattern shows there is no oddity in the early year of 2005 and 2014, So there is possibility the hotspot in early January 2005, probably caused by the prevailing northeasterly winds, sustained haze transport from Riau to the region unlikely at that time of year [9]. Meanwhile, in 2014 there is a climate phenomenon called Madden Julian Oscillation (MJO) which also maybe causes the increasing severity of Riau’s dry season from January up to March 2014 [4].

3.3. SVD analysis number hotspots in Indonesia with local SST
The local SST uses in this research are Karimata Strait’s and Java Sea’s SST. The analysis results are Karimata strait SST is related to the hotspots in the northern part of Sumatra. In contrast, the Java Sea's SST is connected to the hotspots in Kalimantan and the southern part of Sumatra. Therefore, further analysis of both SST was only carried out with the respective area. Figure 11 shows the spatial pattern of HCM from the results of the SVD analysis to the northern part of Sumatra and the Karimata Strait’s SST with lag-0. The variance explained for the first mode is 99.99% and 0.001% for the second mode. The first mode with variance explained 99.99% is sufficient to represent Karimata Strait's SST’s association with hotspots in the northern part of Sumatra. The second mode is considered not significant.

Figure 10. Second mode temporal pattern of AUSMI and hotspot in Indonesia

![Figure 10. Second mode temporal pattern of AUSMI and hotspot in Indonesia](image10)

Figure 11. First mode HCM of a hotspot in the northern part of Sumatra and Karimata strait’s SST

![Figure 11. First mode HCM of a hotspot in the northern part of Sumatra and Karimata strait’s SST](image11)
Figure 11 shows that hotspots with a higher value of negative correlation are the coastal parts of Riau province. The decrease of Karimata Strait’s SST led to reduced local cloud formation activities, thus reducing rainfall in the surrounding area.

Figure 12 shows a recurring pattern every year where Karimata Strait’s SST will decrease in the early year and increase mid-year. The first mode shows a decrease in Karimata Strait’s SST associated with an established hotspot on the island of Sumatra, which has a hotspot pattern at the early year and mid-year, as in Figure 12.

The second local SST in this research is Java Sea’s SST. The analysis is carried out to Java Sea’s SST together with hotspots in Kalimantan and the southern part of Sumatra. Figure 13 shows the spatial pattern of HCM, which shows the SVD analysis results from the hotspots together with Java Sea’s SST with time lag 0. The variance explained for the first mode is 99.99% and 0.004% second mode. The first mode with variance explained 99.99% is sufficient to represent SPL in the Java Sea and hotspots in the lower part of Sumatra and Kalimantan. The second mode is considered not significant.

Figure 13 shows that Java Sea’s SST is more associated with hotspots in Lampung, South Sumatra, Jambi, West Kalimantan, Central Kalimantan, South Kalimantan, and East Kalimantan. Meanwhile, Figure 13 also shows several hotspots with positive correlations, representing the hotspots that appeared at the beginning of the year. These hotspots are mainly found in Riau province. However, the correlation values are very low, which is in the range of 0 to 0.15.
The temporal pattern in Figure 14 shows a recurring pattern every year where Java Sea’s SST will decrease twice in one year. The first mode shows a decrease in Java Sea’s SST associated with hotspots on the islands of lower Sumatra and Kalimantan, especially in 2004, 2015, and 2019.

4. Conclusion

Land and forest fires in Indonesia have two patterns: the pattern of land and forest fires that occur in the middle of the year and at the beginning of the year. As a consequence of seasonal climate patterns and annual variability in Indonesia, most land and forest fires in Indonesia occur during the dry season in the middle of the year. The increased number of hotspots in Indonesia is greatly influenced by the dry season's length and the final month of the dry season in the particular year.

This research shows that AUSMI with an east wind pattern is a pattern that is more associated with hotspots in Indonesia, especially years when zonal winds enter an upward phase more slowly. Karimata Strait’s SST is associated with hotspots in the coastal part of Riau province that occurred at the beginning of the year, and Java Sea’s SST is associated with hotspots in the provinces of Lampung, South Sumatra, Jambi, West Kalimantan, Central Kalimantan, South Kalimantan, and East Kalimantan. This result can be used as additional information to the causes of hotspots that occurred annually in Indonesia to make the early warning system of forest fire better in the future.

Acknowledgments

Acknowledgment is given to the National Oceanic and Atmospheric Administration (NOAA) for the OISST dataset, Agency for Meteorology Climatology and Geophysics of Indonesia for the hotspot dataset, and invaluable assistance as well as the Department of Mathematics of IPB University for the strong support.

References

[1] Björnsson H and Vanegas S A 1997 A Manual for EOF and SVD Analyzes of Climate Data Department of Atmospheric and Oceanic Science and Center for Research and Global Change Research McGill University

[2] Chelton D B, Esbensen S K, Schlax M G, Thum N, Freilich M H, Wentz F J, Gentemann C L, Mc Phaden M J, and Schopf P S 2001 Observations of coupling between surface wind stress and sea surface temperature in the eastern tropical Pacific J. Climate, 14, 1479–1498

[3] Dennis R A 1999 A review of fire projects in Indonesia, 1982–1998. CIFOR, 105p.

[4] Eguchi N, Kodera K, and Nasuno T 2015 A global non-hydrostatic model study of a downward coupling through the tropical tropopause layer during a stratospheric sudden warming Atmos. Chem. Phys 15, 297–304 doi:10.5194/ACP-15-297-2015

[5] Habibie M N and Nuraini 2014 Karakteristik dan Tren Perubahan Suhu Permukaan Laut di Indonesia Periode 1982-2009 Jurnal Meteorologi Dan Geofisika. 15(1) 37-49

[6] Harris N, Minnemeyer S, Stolle F, and Payne O 2015 Indonesia’s fire outbreaks producing more daily emissions than entire US economy World Resources Institute (available online at...
https://www.wri.org/blog/2015/10/indonesia-sfire-outbreaks-producing-more-daily-emissions-entire-us-economy

[7] Harrison M E, Page S E, and Limin S W 2009 *The global impact of Indonesian forest fires* Biologist 56 (3)

[8] Kajikawa Y, Wang B and Yang J 2009 *A multi-time scale Australian monsoon index* International Journal of Climatology 30(8) 1114-1120

[9] Koplitz S N, Mickley L J, Jacob D J, Marlier M E, DeFries R S, Gaveau D L A, et al. 2018 *Role of the Madden-Julian Oscillation in the transport of smoke from Sumatra to the Malay Peninsula during severe non-El Niño haze events* Journal of Geophysical Research: Atmospheres 123 6282–94 doi:10.1029/2018JD028533

[10] Kullgren K and Kim K-Y 2006 *Physical mechanisms of the Australian summer monsoon: 1. Seasonal cycle* J. Geophys. Res. 111 D20104 doi:10.1029/2005JD006807.

[11] Kusuma D, Murdimanto A, Aden L, Sukresno B, Jatisworo D, and Hanintyo R 2017 *Sea Surface Temperature Dynamics in Indonesia* IOP Conference Series: Earth and Environmental Science 98. 012038. 10.1088/1755-1315/98/1/012038.

[12] Navarra A and Simoncini V 2010 *A Guide to Empirical Orthogonal Function for Climate Data Analysis* Springer

[13] Nurdiati S, Sopaheluwakan A, and Septiawan P 2021 *Spatial and Temporal Analysis of EL NINO impact on Land and Forest Fire in Kalimantan and Sumatra* Agromet Vol 35: 1-10, doi: 10.29244/j.agromet.35.1.1-10

[14] Napitu A M, Gordon A L, amd Pujiana K 2015. *Intraseasonal Sea Surface Temperature Variability across the Indonesian Seas* Journal of Climate 28(22) 8710-27

[15] Purnomo H, Shantiko B, Sitorus S, Gunawan H, Achdiawan R, Kartodihardjo H and Dewayani A A 2017 *Fire economy and actor network of forest and land fires in Indonesia*. For. Policy Econ 78 21–31.

[16] Septiawan P, Nurdiati S and Sopaheluwakan A 2019 *Numerical Analysis using Empirical Orthogonal Function Based on Multivariate Singular Value Decomposition on Indonesian Forest Fire Signal* IOP Conf. Ser. Earth Environ. Sci. 303 012053.

[17] Sheldon TL and Sankaran C 2017 *The Impact of Indonesian Forest Fires on Singaporean Pollution and Health* Am Econ Rev 107(5):526-9. doi: 10.1257/aer.p20171134

[18] Soo H L 2015 *General Rainfall Patterns in Indonesia and the Potential Impacts of Local Sea’s on Rainfall Intensity* Water 7 1751-68

[19] Sun S, Fang Y, Zu Y, Liu B, Tana, and Samah A A 2020 *Seasonal Characteristics of Mesoscale Coupling between the Sea Surface Temperature and Wind Speed in the South China Sea*, J. Climate, 23, 625-638

[20] World Bank 2016 *The cost of fire: An economic analysis of the 2015 fire crisis*. Indonesia Sustainable Landscapes Knowledge Note 1 World Bank Jakarta