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ACTIVE ZONES DETECTION OF SEA SURFACE TEMPERATURE FOR DROUGHT EVENTS IN EAST NUSA TENGGARA INDONESIA USING BOOTSTRAP

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ABSTRACT

Nino is a global phenomenon that causes the rainfall in Indonesia to decrease significantly and is one of the factors which causes drought. Drought is a natural event and can be defined as the condition of water supply deficiency which lasts for a long period until the rainy season arrives. East Nusa Tenggara is known as one of the most drought-striken provinces in Indonesia. The standardized precipitation index (SPI) is a method to characterize drought events, and this paper used it as the basis of determining drought events in East Nusa Tenggara. Furthermore, composite maps of sea surface temperature (SST) showing the active regions associated with drought in East Nusa Tenggara are identified by bootstrap method. In order to overcome the bias of the mean maps, this research developed anomaly maps. The maps indicate that the North part of West Nusa Tenggara and Bali show significantly low level of sea surface temperature on one to two months prior to the occurrence of the event. The regions around Kalimantan and Sulawesi have been detected as active zones as well in particular of a month before drought happens.

Keywords: anomaly, bootstrap, composite maps, SST.

INTRODUCTION

Drought is a natural event caused by lack of water and lasts for long period until rainy seasons arrives. This phenomenon cannot be separated from the deviation of weather condition instead of the normal condition. The impact of the deviation often results on decreasing of precipitation in a certain area. According to [1], drought is closely related to as significantly reduced rainfall intensity, above normal temperature, lack of soil humidity, and also insufficient water supply.

East Nusa Tenggara is one of Indonesian provinces which is highly vulnerable to drought events. As reported in [2], drought oftenly occurs in East Nusa Tenggara with total amount of 15 districts run into it. This may adversely impact to many aspects especially in agriculture sector. Drought often leads to crop failure as most of the rainfed and rice field are heavily dependent on water.

One of the methods that can be used to analyze drought occurrence is Standardized Precipitation Index (SPI), which evaluates and detects drought based on the specified value. One of the advantages of using SPI is it can be calculated for different time scales. The SPI is also more simple than Palmer drought severity index and able to provide early drought warning along with the assessment about its severity [3].

Drought events are usually indicated by a change on meteorolgical pattern, in which it may be different among events which creates diffuculty on predicting drought. Composite maps can give a description of drought by describing the corresponding meteorological pattern within the whole period, thus it can identify different pattern in the area of the map as it supposed to be [4]. This research used bootstrap of [5] to create the map with a specific level of significance. The study showed that bootstrap method can exempt the parametric assumptions of the originating data. The study by [4] also composes a composite map with anomalous data. The usage of anomaly data provides higher accuracy and averts bias due the seasonal trend on the data.

This research analyzed the meteorological patterns of sea surface temperature over Indonesian territory prior to the occurrence of extreme drought in East Nusa Tenggara. The analysis performed mean and median anomaly maps compared with without anomaly maps. Active zones associated with the events are investigated as well.

LITERATURE REVIEW

Standardized precipitaion index

Mckee in 1993 developed the Standardized Precipitation Index, which is a method for measuring rainfall deficiency on each period. Classification of meteorological drought scale using the SPI according to [6] is listed in Table-1.

Table-1 SPI classification.

SPI	Drought category
$-1.00 \leq SPI \leq 1.00$	Near normal
$-1.50 \leq SPI \leq -1.00$	Moderate dry
$-2.00 \leq SPI \leq -1.50$	Severe dry
SPI <-2.00	Extreme dry

Bootstrap

Bootstrap is a method of simulating sampling of a data with or without replication [5]. Each bootstrap sampling generates different values. Theoretically, since samples are taken repeatedly then the asymptotic nature of the bootstrap distribution will be close to the actual distribution of data. The bootstrap resampling method is used to obtain the sample parameters.

The interval estimation θ is obtained from percentile bootstrap approach. Once $\hat{\theta}_b^*$ for each replication is obtained, the estimators are then sorted as $\hat{\theta}_1^* \le \hat{\theta}_2^* \le \ldots \le \hat{\theta}_B^*$. The upper and lower limits of the confidence intervals are $\left[\hat{\theta}_{low}, \hat{\theta}_{up}\right] = \left[\hat{\theta}_{B.(\alpha/2)}^*, \hat{\theta}_{B.(1-\alpha/2)}^*\right]$. Suppose that the procedure is replicated 1000 times denoted as B = 1000 with significant level α =5%, then the lower bound of the confidence interval is the 25th element and the upper limit of the confidence interval is the 975th element of the sequenced line or $\left[\hat{\theta}_{(25)}, \hat{\theta}_{(975)}\right]$.

Testing the parameters is done by comparing the obtained values with the confidence interval. The hypothesis is rejected if the tested value lies outside the confidence interval, which means the tested value is significant. In the composite map, it is an indication that the region is an active zone.

Anomaly

Anomaly is basically a method that searches for a data that deviates from a normal set of data. According to [7] states that anomaly is one way to ensure that the results obtained are not biased. Anomalous methods provide more precision on composite maps. The formula to calculate mean anomaly is shown as follows:

$$f_i^{'}(x,y) = f_i(x,y) - Mean_y \tag{1}$$

With:

$f_i^{'}(x,y)$ = Anomalous data observation at time-x and period-y

$f_i(x,y)$ = Data observation at time-x and period-y

$Mean_y$ = The average value of data observation in period-y

y = Monthly period (1,…,6)

i = 1,…,102

calculation with median provides more appropriate results than calculation with mean, in particular for non-normally distributed cases. It is because median is more suitable if the data has skew pattern. Median is also more robust against outlier [8]. The formulas between mean and median are the same as expressed in equation (1), ecepts that the mean is replaced by median.

Sea surface temperature

Sea surface temperatures are highly affected by the global climate change [9]. The increasing sea surface temperatures level results in rising of seawater evaporation. Water vapor generated from evaporation of seawater produces rainfall that triggers the risk of heavy rain and snowfall (see indicators of heavy rainfall and tropical storm activity). The alteration in sea surface temperatures can also lead to shift of rainfall cycles which allow the potential to cause drought in certain areas.

Composite and synoptic maps

The composite map is an informative map to illustrate the same event through the mean calculations on the variables. The map is used for a particular region in order to determine the region on the map showing a different pattern from the usual pattern to the occurrence (in this study the drought in NTT province). [7] declares that each grid point on a composite map is the mean of several values whose distribution is known.

Meteorological drought

Meteorological drought is a drought associated with the lack of precipitation in one season. This impacts to the deficiency of soil moisture and the amount of stored water (lower than normal conditions) [10].

Precipitation

Precipitation is a set of water that falls to the surface for a certain period. Precipitation rate often measured in mm unit. The rain intensity criteria can be categorized into 4 parts, the intensity of light rain with intensity 5-20 mm / day, moderate rain with intensity 20-50 mm / day, heavy rain intensity 50-100 mm / day, and very heavy rain with intensity 20 mm or more per day [11].

RESEARCH METHOD

Data and variables

There are two different datasets used in this research i.e. observation data and satellite data. The observation data used in this research is daily rainfall data obtained from the official website of the Agency for Meteorology, Climatology and Geophysics (BMKG) Indonesia spanning from the period of 1999-2015. Data from nine different meteorological stations located in nine regions in NTT have been collected.

The satellite data is Era-Interim reanalysis dataset obtained from www.ecmwf.int. The Era-Interim reanalysis data is chosen among other sources of satellite data due to some consideration especially about the quality of the data [[4]. The dataset consists of sea surface temperature data within the same period research method.

Steps of the analysis

The steps of analysis conducted in this research are as follows:

a) Describe the daily rainfall data in six islands
b) Calculate and determine the extreme month of drought on daily rainfall data during dry season (April-

September) for 7 stations using SPI method with the following steps:

- aggregate daily rainfall data to monthly precipitation data per station. Each monthly precipitation data per station will be converted into monthly SPI per station.
- extreme drought periods determination

c) Set the grid along Indonesia with latitude 5° North to 10° South and longitude 100°-150° East. Each grid represents coordinate of 0.25°.

d) Calculate the mean and median anomalies for sea surface temperature.

e) Perform the descriptive statistics for both mean and median anomalies data

f) Apply bootstrap to the sea surface temperature data at the time of M-2 (2 month before) and M-1 (1 month before) occurrence of extreme drought in East Nusa Tenggara with the following steps:

- Conduct a bootstrap resampling of sea surface temperature data by taking samples as much as the number of extreme drought dates found in step 2. The resampling process is done 1000 times.
- Calculate the mean of the data collected for each resampling process and obtain a vector of mean bootstrap with the size of 1000. The mean of each resampling process is sorted.
- Calculate the percentile of the bootstrap mean vector as the significance bound. An α value is required in order to make significance bound. The α level indicates that the SST at the corresponding zone is significantly different or not (depending on th etest result) with the climatological mean of SST. The present study will use α=1%, 2%, 5% and 10% values to build the significance limit.

g) Identify the actives zone by mean significance test which is obtained in step 4 and compare with the significance bound that has already obtained in step 6.

h) Repeat steps 4 until 7 for all coordinates.

i) Develop the composite map of sea surface temperature in Indonesia at M-2 and M-1 prior to drought occurrence in East Nusa Tenggara, where M indicates month.

j) Repeat steps 4 until 9 for mean anomaly sea surface temperature and median sea surface temperature data.

RESULTS AND DISCUSSIONS

Daily precipitation data pre-processing

The precipitation data obtained from the webpage http://www.dataonline.bmkg.go.id spans from the period of 1999 to 2015 has missing value. Those missing values are coded into 8888 and 9999; therefore pre-processing steps are required such as data imputation for missing value data. Imputation of daily precipitation has been done by [14], which means that this study uses daily precipitation data that has been imputed by [14].

Descriptive statistics of daily precipitation in east Nusa Tenggara

Analysis of daily precipitation in East Nusa Tenggara is required in order to have an overview about rainfall condition in East Nusa Tenggara. The descriptive statistics of precipitation data is also necessary to be performed in order to determine the drought period in East Nusa Tenggara. The chosen periods will be used as the basis of running bootstrap for developing composite maps of other variables (sea surface temperature and mean sea level pressure). Descriptive statistics on daily rainfall patterns in six islands of East Nusa Tenggara can be performed using bar charts obtained from the average monthly rainfall for each island during the period 1999-2015 as shown in Figure-1 as follows:

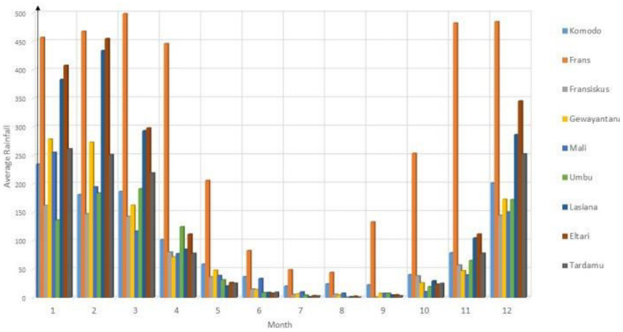

Figure-1. The average monthly precipitation in east Nusa Tenggara.

It is known from Figure-1 that the highest monthly rainfall happened in January and the lowest happened in August. Also from Figure-1 we can see the unusual pattern as happen in Indonesia in general, i.e. October is supposed to be rainy season; however the monthly rainfall in October is less than April and May which are the dry season in Indonesia. Months of drought events in East Nusa Tenggara evaluated from the SPI can be seen in Table-2 below.

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Table-2. Drought occurrence period in east Nusa Tenggara.

Year	Month	Komodo	Frans	Gewa	Umbu	Lusiana	ELtari	Tardamu
1999	May	-1.16	-1.84					
2011	April	-1.60					-1.24	-1.39
2011	Sept		-1.04					
2002	April							-1.57
2002	May	-1.43	-1.49					
2002	June		-2.36					
2002	Sept		-1.43					
2003	April			-1.19				
2004	April		-1.66	-1.19	-1.53	-1.57		-1.39
2004	July		-1.57					
2004	Aug		-1.08					
2005	May		-2.02					
2005	May	-1.57	-1.50					
2007	May		-1.27					
2009	May		-1.42		-1.57	-1.54	-2.48	
2011	May		-2.36					
2012	May	-1.16						
2012	May		-1.19					
2014	May	-1.57						
2015	May		-1.19					
1999	May	-1.16	-1.64					

Table-2 shows that there are total 21 periods of drought in East Nusa Tenggara. Drought happened in at least one region in East Nusa Tenggara. Those periods will be used to generate composite map sea surface temperature in Indonesia.

Composite maps for weather components

The composite map in East Nusa Tenggara is derived by utilizing dataset collected from 9 meteorological stations. As described in Table-6 that during the period of 1999-2015 there were 21 drought events in East Nusa Tenggara. Analysis of weather conditions in the atmosphere cannot be seen vertically only based on the point of coordinates of the province. It is known that East Nusa Tenggara is located at 6^o-11^o latitude and 118^o-125^o longitude. The descriptive statistics for the weather variables will be performed for 4 grid points close to that point as shown in Figure-2 below.

Figure-2. Coordinate of east Nusa Tenggara

From those 4 coordinate, the sea surface temperature data along the East Nusa Tenggara region will be obtained. Figure-3 presents a boxplot describing the sea surface temperature at 4 point coordinates.

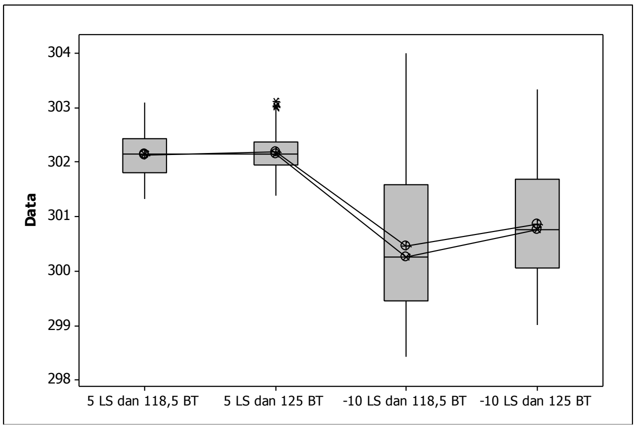

Figure-3. Sea surface temperature in east Nusa Tenggara.

Figure-3 shows that the sea surface temperature around East Nusa Tenggara varies depending on the latitude position. The Sea Surface temperature at the North part of the island is higher than the south part. From the boxplot it was found that sea surface temperature within the observed periods at 4 point coordinates tend to skew showing that the distribution is away from normal. [6] stated that anomaly is one of the ways to ensure that the results are unbiased. Figure-4 shows the boxplots of mean anomaly data or sea surface temperature.

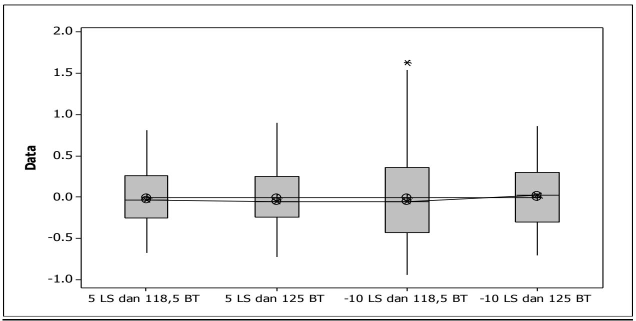

Figure-4. Mean anomaly of sea surface temperature in East Nusa Tenggara.

Figure-4 shows sea surface temperature data which has been reduced by mean. The figure reveals that the anomaly of sea surface temperature at the coordinate -10 S; 118.5E happened frequently with an experience of an extreme anomaly showing by star out of the box. Furthermore, composite maps showing three different conditions will be developed i.e. mean map, mean anomaly map and median anomaly map. The process is begun with bootstrap analysis to investigate the active zones. This paper develop the maps for one and two months prior to the drought occurrence, denoted as M-1 and M-2 consecutively. Figure-5 is given in order to illustrate the bootstrap process, in which the sampling distribution of surface temperature at M-1 of drought event in East Nusa Tenggara is known, as well as the procedure of testing the hypothesis. Note that figure 5 only perform bootstrap result in at a single point using 1000 replications. Indeed, the composite map is developed after performing bootstrap for all grid points.

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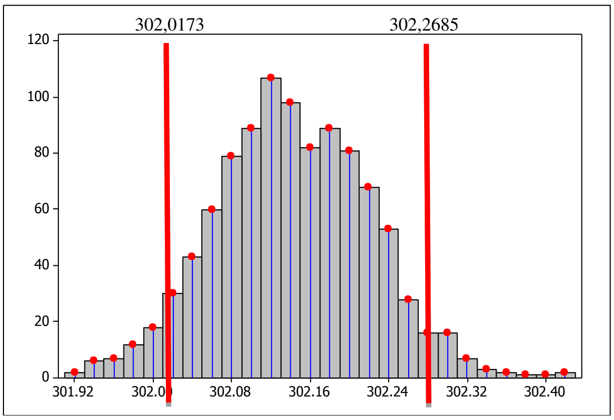

Figure-5. Bootstrap histogram of sea surface temperature M-1 at 118,5° East and 5° South.

Figure-6 shows the result of bootstrap process for mean map. The mean value of sea surface temperature at M-1 of drought event in East Nusa Tenggara is 302.0097. The 10% significant level yields on 302.0173 and 302.2685 as the lower and upper bound respectively. Since the mean sea surface temperature is outside the confidence bound for 10%, hence sea surface temperature at this coordinate point is significant at the level of 10%, which also means that the coordinate point is candidate of active zone. This evaluation process is applied for all grid points. As the results, the composite maps can be seen in Figure-6.

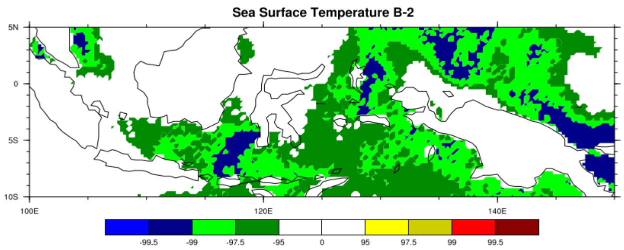

Figure-6. Mean map of SST on M-2.

Figure-6 shows a composite mean map of Sea Surface Temperature on 2 months prior to drought event in East Nusa Tenggara. It is known that almost all sea areas in Indonesia have low or cold sea surface temperature, but the resulting map has not shown a good map to describe drought due to many areas In Indonesia indicating the active zone, therefore a composite map with anomaly data is required. The composite map of M-2 with mean anomaly data is presented in Figure-7 as follows:

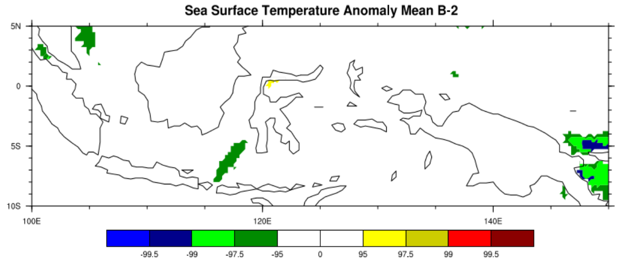

Figure-7. Mean anomaly map for SST on M-2.

The anomaly map as shown in Figure-7 shows regions over Indonesia which has clear anomaly i.e. a condition that significantly different than the normal condition. From this map, the active zones that really give a signal of drought event can be identified. The active zone in Figure-7 such as the area around Singapore, Papua New Guinea, and the area above West Nusa Tenggara shows cold sea surface temperature which means that if the sea surface temperature in the area indicates significantly low level, then in the next two months there will be drought in East Nusa Tenggara. Furthermore, a composite map of sea surface temperature two months before drought with median anomaly data is presented in Figure-8.

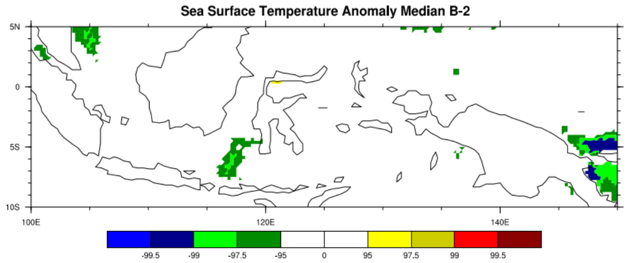

Figure-8. Median anomaly map for SST on M-2.

Composite map generated with median anomaly gives almost no difference in active zone as composite map generated in Figure-7. The area around Singapore, Papua New Guinea, and the area above West Nusa Tenggara are the active zones as presented by composite map of M-2 shown in Figure-8. Figure-9 below presents composite map a month before drought event in East Nusa Tenggara.

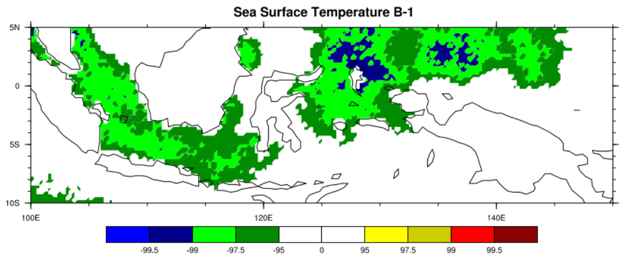

Figure-9. Mean map for SST on M-1.

Composite map in Figure-9 shows that area of Karimata Strait (between Sumatra and Borneo), Sea of

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Java, and Singapore are active zones. There are some differences on the pattern between M-2 to M-1, where the low temperature tend to shift from south-east to north-west part of Indonesia. For instance, the area around Papua gave a sign of active zone at two months before drought occur, however the temperature is getting warmer to normal at a month before drought occurrence.

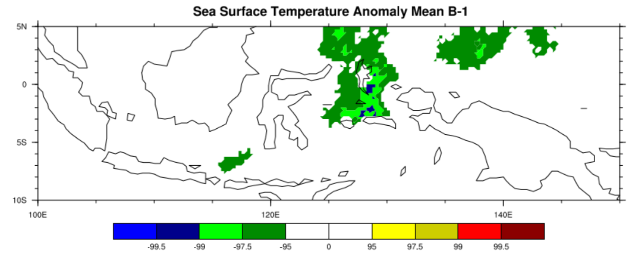
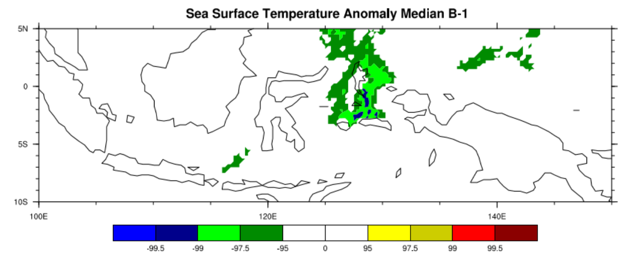


Figure-10. Mean anomaly map for SST on M-1.

Figure-10 shows the composite map of sea surface temperature a month before drought occurrence with mean anomaly data. The results in Figure-9 illustrate areas that significantly address patterns different from the usual such as north area of West Nusa Tenggara, Area around Ternate Island, Maluku, and North area of Papua Island. Those are sign of cold sea surface temperature. The next one is composite map with median anomaly data which is presented in Figure-11 as follows:



(f)

Figure-11. Median anomaly map for SST on M-2.

The composite maps generated with median anomalous data appear to have almost no difference in active zones as composite maps generated with mean anomalous data. Results of composite map a month before drought with median anomaly data showed active zone in the area above West Nusa Tenggara, area around Ternate and Maluku Island, and area North of Papua Island with cold sea surface temperature condition. Similar pattern between mean and median maps indicate that the sea surface temperature over Indonesia is normally distributed.

The accuracy level calculation for the composite map of sea surface temperature at any time generated through the significance test approach of each month of drought with the interval of 1000 mean resampling bootstrap. The determination of the accuracy level is determined through the process of testing whether the variable of sea surface temperature for each drought month will be the same as the average variable of sea surface temperature during the regular month in the dry season. The Table-3 below will present the accuracy by taking 1 point of coordinates used as an example.

Table-3. Accuracy level of sea surface temperature in coordinate 5° South and 118,5° East.

Sea surface temperature		
Data	**M-1**	**M-2**
Without Anomaly (%)	57.14285714	57.14285714
Mean Anomaly (%)	100	100
Median Anomaly (%)	100	100

Table-3 shows the value of sea surface temperature accuracy at 1 month before the drought and 2 months before the drought occurence in East Nusa Tenggara for the original data, mean anomaly data, and median anomaly data. The testing process based on the significance test between sea surface temperature value during the month of drought with the bootstrap resampling interval found that the accuracy of M-1 and M-2 for the original data gives 57.14% accuracy, while for mean anomaly and median anomalies Gives 100% accuracy. The testing process is performed for all coordinate points. Comparison of the number of significant coordinate points between data without anomalies, mean anomalies, and median anomalies is presented in Table-4 below:

Table-4. Total of significant coordinate points for sea surface temperature M-1.

Significance bound	Without anomaly	Mean anomaly	Median anomaly
$\hat{\theta} < \theta_5$	101	11	15
$\theta_5 < \hat{\theta} < \theta_{10}$	472	40	32
$\theta_{10} < \hat{\theta} < \theta_{25}$	1871	218	195
$\theta_{25} < \hat{\theta} < \theta_{50}$	1744	900	566
$\theta_{950} < \hat{\theta} < \theta_{975}$	0	0	0
$\theta_{975} < \hat{\theta} < \theta_{990}$	0	0	0
$\theta_{990} < \hat{\theta} < \theta_{995}$	0	0	0
$\hat{\theta} > \theta_{995}$	0	0	0

Based on Table-4 we can see a comparison of the number of significant points in the composite map of sea surface temperature 1 month prior to drought in East Nusa Tenggara between data without anomaly, mean anomaly data, and median anomaly. Comparison of Table 8 shows that there is a significant point change between data without anomalies with anomalous (mean or median) data such as $\hat{\theta} < \theta_5$ significant limits of 101 significant points for data without anomalies, 11 significant for mean anomaly data, and 15 significant points for median anomaly data. It means that the usage of anomalous data can prevent from bias cases in composite maps.

CONCLUSIONS

Bootstrap approach has been applied to generate composite maps showing the active zones associated with the drought events in East Nusa Tenggara. The bootstrap clearly indicated that the SST has normal distribution, which makes it feasible to infer the significant bounds using the percentile approach. The composite maps analysis for sea surface temperature showing that the active zones are Northern area in West Nusa Tenggara and Bali with low sea surface temperature (cold). The anomaly map can reduce the bias of the mean maps significantly, leading to a clear pattern as well as locations of the active zones. The mean and median maps (including the anomaly) show a similar pattern, which is also an indication of normally distributed SST.

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