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Eight-Day Daytime Land Surface Temperature Pattern over Peninsular Malaysia

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Abstract*: *The monitoring of land surface temperature (LST) can assist scientists to better understand the possible effect of climate change on land cover types and in conducting appropriate analysis. The earth's annual temperature has moved up and down a few degrees Celsius, including Malaysia, over the past few million years. The location of Malaysia near the equator line and experiences tropical monsoon season were important to take into consideration to the LST changes. In this paper, the eight-day LST time series data for 14-year period (Jan 2003 – Dec 2016) was downloaded from Moderate Resolution Imaging Spectroradiometer (MODIS) website with two types of satellites which are Terra and Aqua. This study focused on two gridded areas in Peninsular Malaysia; the first one which is exposed to North East monsoon, namely super region 21 and another one to South West monsoon, which is super region 26. These two areas are selected due to they being the largest land area covered within the grid relative to other grids. The objective of this study is to compare the eight- day daytime LST pattern between two monsoons with different land cover types for both satellites. Analysis such as cubic spline function with the annual periodic boundary condition and weighted least square (WLS) regression were performed to extract annual seasonal trend for the areas covered. The results of LST showed most of the gridded areas experience similar seasonal pattern for each year but different pattern were discovered when both monsoons were considered. Moreover, the LST trends also changed according to the land cover types over the study period.

Keywords*: *Cubic spline, gridded data, Land Surface Temperature (LST), MODIS, time series, Terra and Aqua satellites.

I. INTRODUCTION

Climate change and global warming are crucial phenomenon that are of interest to many scientists. It is also of importance to the society to be aware of any possible change in the environment as it will directly affect the daily activities and plans [1]. Nowadays, events related to extreme whether condition occurs more and more frequent such as extreme rainfall events and irregular rising and falling in temperature. These events are believed to be due to climate change which is a global phenomenon. Climate change in Malaysia has also been a crucial issue to be studied [2-4].

Malaysia is located near the equator line and experiences tropical monsoon weather, being hot and humid throughout the year with average temperature of 27 °C. As of 2016, National Centres for Environmental Information (NOAA) [5] reported that the temperature measured based on land has increased this year. Malaysia Meteorology Department (MMD) [6] also reported the same result in which 2016 was recorded as the warmest year in this country with a mean temperature of 27.66 °C. This value exceeded the previous temperature recorded in 1998 which was 27.60 °C .The highest temperature, 39.3 °C, was recorded at Batu Embun, Pahang on 10 April 2016, while the lowest temperature, 19 °C , was at Kuala Krai, Kelantan on 22 February 2016. Highest temperature change in a day, 17.3 °C, was recorded at Kerteh, Terengganu on 16 November 2016, while lowest change in a day, 1.2 °C, was at Kuala Krai, Kelantan on 8 April 2016. These irregular phenomenon also highly influenced by natural climate variability such as Super El Nino which typically occurred at the beginning of the year until the middle of 2016 and La Nina which started in the third quarter of 2016. Apart from that, there are two monsoon wind seasons in this region, the North East (NE) monsoon usually occur from November to March and the South West (SW) monsoon from May to September each year. The NE monsoon brought heavy rain especially to the states on the east coast of Peninsular Malaysia and west of Sarawak, while SW Monsoon relatively showed drier period particularly to west coast of the Peninsular Malaysia. The transition period between these two monsoons is known as the intermediate season in which the heavy rainfall usually occur at these period. Due to these irregular phenomenon, we also included year 2016 in this study to compare the changes in LST with the results reported by NOAA and MMD. There have been many studies which proved that monsoons contribute to the change in the weather trend. For example, studies on rainfall trend during southwest and northeast monsoon over Peninsular Malaysia show that for most of the stations, rainfall trend for the number of wet days has significantly decrease during extreme events [7]. Thus, it is important to take into consideration these two monsoons in studying changes in the weather.In contrast, there is not many studies on temperature in Malaysia has been conducted, believed to be due to not much change in temperature throughout the year.

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Thus, this motivates this analysis to be performed. Land Surface Temperature (LST), which is known as one of the important factors contributing to climate change is the main focus in this study. LST has been identified as one of the key variables or most important parameter in monitoring climatological processes, vegetation, urban climate and environmental studies [8]-[14]. The LST data is freely available on Moderate Resolution Imaging Spectroradiometer (MODIS) website. Two satellites are used to provide data which are Terra (MOD11A) (starts at 10.00 AM) and Aqua satellite (MYD11A) (starts at 1.00 PM). Data was downloaded based on location of area of interest correspond to latitude and longitude.The data obtained from satellite may not be 100% accurate due to several factors such as cloud condition and rainy season, thus an appropriate method and analysis should be designed to obtain a good and accurate results in describing the actual temperature. This study is focused on two gridded areas in Peninsular Malaysia that are exposed to NE and SW monsoons for the 14-year period (Jan 2003-Dec 2016). The objective of this study is to compare the LST trend between two monsoons periods based on both satellites. In this study, we also consider another factor that have contribute to the changes of the LST which is land cover types. Data analysis methods which are used in this study are cubic spline function with the annual periodic boundary condition and weighted least square (WLS) regression to extract annual seasonal trend for the areas covered.

II. STUDY AREA

At the beginning of this study, we created 34 super-regions (part of Thailand, Peninsular Malaysia and Singapore) of dimension 105 x 105 (11,025) pixels with the size for each super region is approximately 104 x 104 km as show in Fig. 1. However, this study only focused on Peninsular Malaysia with two super regions which are super region 21, centered at Jengai, Terengganu with latitude 4.538 and longitude 103.094 and super region 26 centered at Sepang, Selangor with corresponding latitude 2.788 and longitude 101.724. These super regions are selected due to the largest land area covered within the grid relative to other grids and exposed to two monsoon seasons. In order to improve the accuracy of the temperature data, the gridded data size of the super regions are narrowed down to a small region, from 25 (5 by 5) regions to nine (3 by 3) sub-regions and each sub-region has 49 (7 by 7) pixels. Super-region IDs were ordered on the map by decreasing latitude, from east to west.

We also highlighted the LST trend for two super regions which were then compared according to the different land cover types as stated in Table 1 [15-16] Then, two sub regions were chosen from selected super regions to compare the LST changes using the fitted cubic spline function as well as to represent the whole super regions. Detailed analysis will be discussed in the next section.

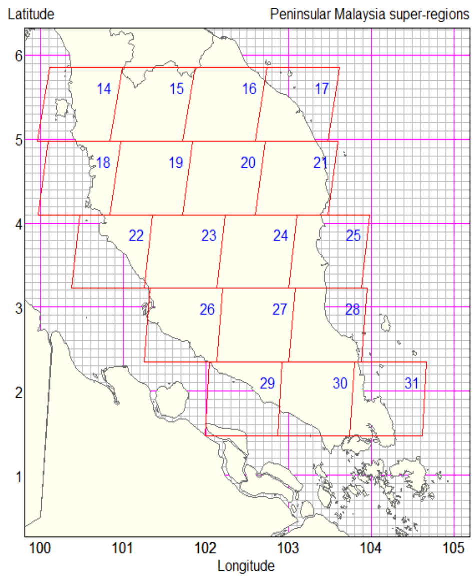


Fig. 1. Map of gridded boxes for Peninsular Malaysia

No.	Label
1	Cropland/Natural vegetation mosaic
2	Evergreen Broadleaf forest
3	Croplands
4	Woody savannas
5	Urban and built-up
6	Savannas
7	Water
8	Permanent wetlands
9	Mixed forest
10	Barren or sparsely vegetated
11	Grasslands
12	Deciduous Broadleaf forest
13	Closed shrublands
14	Open shrublands
15	Deciduous Needleleaf forest
16	Snow and ice
17	Evergreen Needleleaf forest

III. METHODOLOGY

Cubic spline function is proposed to be applied in this study due to the fact that there is not much change in annual temperature seasonal pattern for LST data. Cubic spline function is one of the semi parametric approach which one of the general assumptions is both of the response and predictor variable are continous, hence may be used to obtain the time series in a smooth form and continuosly between each data points. Detailed description and procedure of the method used are given in [12]. The cubic spline function is given in equation

$$s(t) = a + bt + \sum_{k=1}^{p} c_k (t - t_k)_+^3 \qquad (1)$$

where t denotes time $t_1 < t_2 < ... < t_p$ are specified knots and $(t-x)_+$ is $(t-x)$ for $t > x$ and 0 otherwise. The smoothness of the joint between points should satisfy the continuity of the first and second derivatives of the above function which given in the following equations:

$$s'(t) = bt + 3\sum_{k=1}^{p} c_k (t - t_k)_+^2 \qquad (2)$$

$$s''(t) = b + 6\sum_{k=1}^{p} c_k (t - t_k)_+ \qquad (3)$$

There are many types of cubic splines, but this study used natural cubic spline function with the assumption that the second derivative equal to zero at the endpoints as given in the equation 4. In order to make the quadratic and cubic coefficients of the spline function to be 0 for $t > T_0$ and $t < T_p$, a special annual periodic boundary condition are required which given in the Equation 4 and 5, where t_1 and t_p are the location of the first knot and the last knot respectively.

$$\sum_{k=1}^{p} c_k = 0 \qquad (4)$$

$$\sum_{k=1}^{p} c_k t_k = 0 \qquad (5)$$

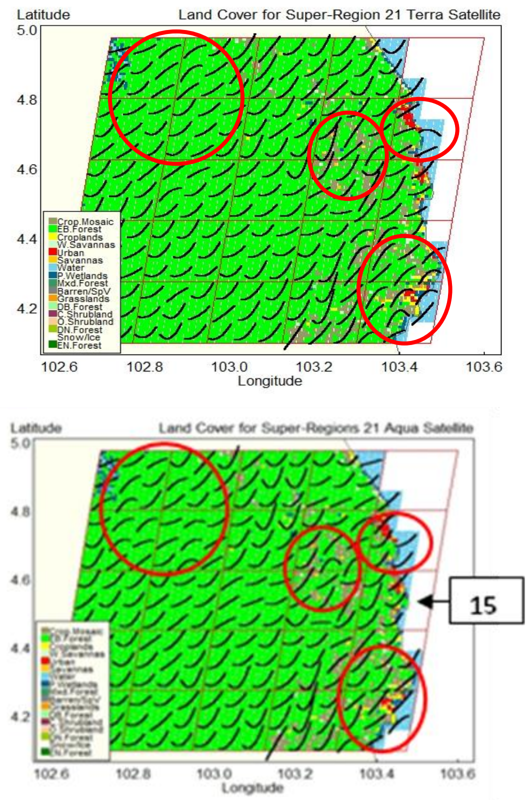
Nevertheless, there are most common problems arises in using this method which are to identify the suitable number of knots and its location. The number and the location of knots are determined by the user and it relies on the changes of the LST trend. A quick changes in the LST trend implies a high number of knots and vice versa [17]. Therefore, determination of the number of knots is important as this improves the accuracy of the estimates. We used eight knots when comparing the eight day LST and four knots for comparing the LST trend for each year in this study based on analysis done by [12] at Thailand as we believed the temperature in Peninsular Malaysia does not differ much from the temperature in Thailand. Several assumptions were considered to allocate the knots which are at the beginning and the end of the year and the stability of the data to retain the seasonal pattern between years.In addition, when study about modelling, there are several assumption has to emphasized. In general, when the data are taken from the same source, there would exists correlation between the data, or in other words, we call it autocorrelation. One of the assumption to be satisfied in modelling is the correlation between data points should be independence. Therefore, in this study the autocorrelation has been adjusted in cubic spline function.

IV. RESULT

A. LST Trend related to North East monsoon

In this section, we are going to focus on super region 21 which is primarily exposed to North East monsoon and this gridded area was identified as part of Terengganu and Pahang state as shown in Fig. 2. Fig. 3 illustrated the maps showing the LST trend for 14-year period with different land cover types between Terra and Aqua satellite. Based on these maps, most of the gridded area is covered with evergreen broadleaf forest (EB forest). Both satellites showed the LST of this area possessed quadratic trend (upward or downward) over the period of study whereas the trend increased drastically at crop mosaic area.

Fig. 3. Map for super region 21



(a)(b) Fig. 4. (a) (b) Differences in LST trend between Terra and Aqua satellites for super region 21

- *Seasonal Variation of LST for Terra and Aqua using Cubic Spline Regression Model*

In this analysis, we randomly chose sub region 15 of super region 21 for both satellites to compare the LST trend with rescpect to the land cover types. This sub region predominantly covered by forest and some urban area as shown in Fig. 3. The annual seasonal variation of eight day LST for both satellites using natural cubic spline function with eight knots are shown in Fig. 4 and 5. Sub region 15 is divided into nine domains which were determined based on its geographical location; North West (NW), North (N), North East (NE), West (W), Central (C), East (E), South West (SW), South (S) and South East (SE). The vertical line (x-axis) represents the day for a year from day 1 to day 365. The black points in the graph represent the LST data for eight-day continuously for each year. For simple visualization in comparing the LST trend, these points are plotted along each vertical line to represent the temperature data for eight-day for 14-year. The LST data is only available over land, therefore there is no data recorded for the NE, E and SE subregion for both satellite.

In Fig. 4, seasonal pattern of LST showed the same pattern for all domains except several domain which have different minimum and maximum values of LST. For example, the LST data vary substantially over short periods especially for day 321 and it's next data point which is 329 (end of November) at NW and 305 to 313 (early November) at N domain for Terra satellite. For example, change in LST values around 10 °C - 12 °C in one day are seen to jump to much higher values approximately around 22 °C - 23 °C within just eight days (indicated by arrow in the graph). Therefore, as we can seen in Fig. 4, the temperature started to drop during NW, followed by the other domains, C, W, S and SW domain. This changes may be due to the North East monsoon which started in November. In addition, since N domain is located near the edge of the super region and sea therefore it is more exposed to this monsoon as compared to the other domain Fig. 3 showed that, this domain is covered mainly by urban and crop mosaic.

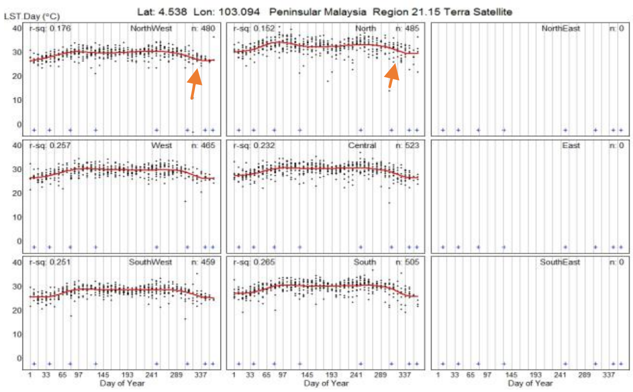
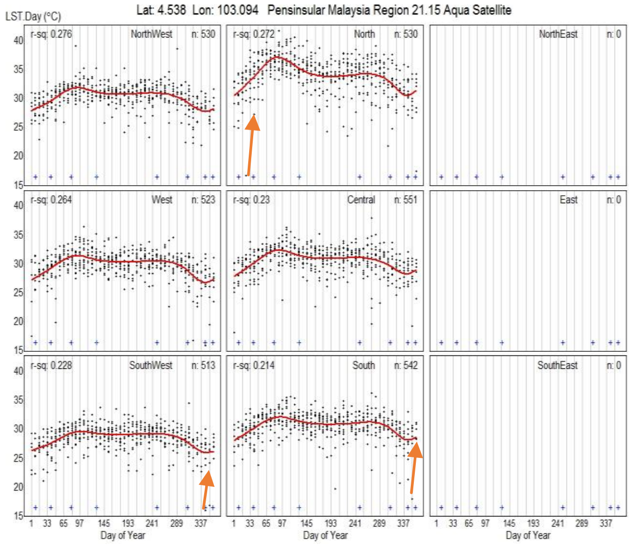


Fig. 5. Annual eight-day seasonal pattern for LST using Terra satellite.

Fig. 5 showed the LST pattern using Aqua satellite. The pattern are quite similar for all domain except for N domain. The fitted cubic spline line at N domain shows there is an increasing values and different pattern of LST during the **Fig. 6. Annual eight-day seasonal pattern for LST using Aqua satellite**



first quarter of the year compared to the other domains. The largest change of LST data on one day to eigth-day occur at day 25 to 33 (end of January) at N domain and end of December (indicated by arrow in the graph) at SW and S domain with the LST values from 15 °C to 25-30 °C. These phenomenon may be due the changes in the monsoon which is believed to cause a drop in temperature. On the other hand, the possible flooding which normally occurs at the end of the year also lead to the drop in LST value. For example, massive flood which occured at the end of December 2013. In addition, the r^2 values show there is not much difference in r values between the domains, hence this implies that the proposed model has the same performance for all the domains.

- *Seasonally-adjusted of Terra and Aqua values with fitted model after adjusting for autocorrelation*

Fig. 6 and 7 show LST trend after they have been seasonally adjusted for autocorrelation using cubic spline regression models for 2003 to 2016. Generally, with reference to the box on the first row (RHS), it can be shown that the LST trend for both satellites are quite similar for each domains with the increasing trend over the years except for W domain in Aqua satellite which shows an upward trend or higher gradient to this domain. This is supported by the p-values > 0.05 for all domains in Terra and Aqua satellite which implies that there are no difference in the changes of LST acrross the year while the p-values < 0.05 for W domain in Terra satellite implies that there is significant difference in the changes of the LST across the year.

The graphs also show that the average LST values for Terra satellite was within 27 °C to 33 °C whereas Aqua satellite shows the average range for LST was 28 °C to 35 °C. Consistently over the year, both satellites show the domain N has the largest LST values with the increasing trend from 2003 to 2016 whereas SW has the lowest LST values. Terra satellite shows LST values for N increased about 1.2 °C (from 31.8 °C to 33 °C) whereas Aqua satellite increased about 2 °C (from 33 °C to 35 °C) across the year. The other domain show there are not much change in LST across the year.

In addition, the highest changes of LST was identified at W domain for both satellites with the values of 0.624 and 1.158 respectively. The lowest changes was found at S for Terra satellite with the values of 0.166 and N domain for Aqua satellite with the values of 0.261.

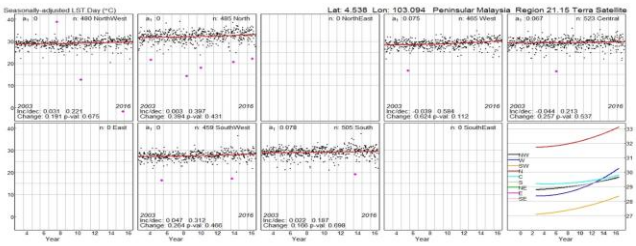


Fig. 7. LST trend (allowing for autocorrelation) after they have been seasonally adjusted using cubic spline regression from Terra satellite.

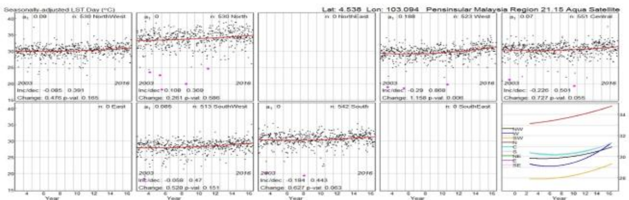


Fig. 8. LST trend (allowing for autocorrelation) after they have been seasonally adjusted using cubic spline regression from Aqua satellite.

B. LST Trend related to South West monsoon

Fig. 8 refer to super region 26 which consist several part of four main states which are Kuala Lumpur, Putrajaya, Selangor and Negeri Sembilan. Fig. 9 shows the differences in LST trend for Terra and Aqua satellite for super region 26. LST trend shows most of the forest area for both satellites have quadratic pattern but not at the other areas. The LST increased drastically at crop mosaic area compared to urban area where at this area, the LST increased with linear trend for both satellites. There are some differences in the LST trend at the top left area of this region (in circle). When the area has various land cover types, for example, urban, cropland and crop mosaic, the LST shows an upward trend whereas Aqua satellite shows a downward trend. In contrast, the LST trend shows a downward trend at urban area compared to Aqua satellite which has an upward LST trend. Thus, the difference in LST trend shows there is no specific pattern with respect to land cover types.

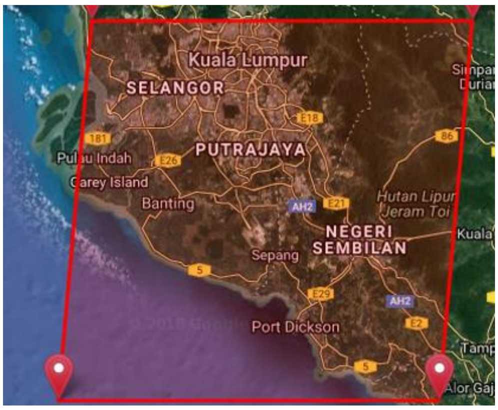
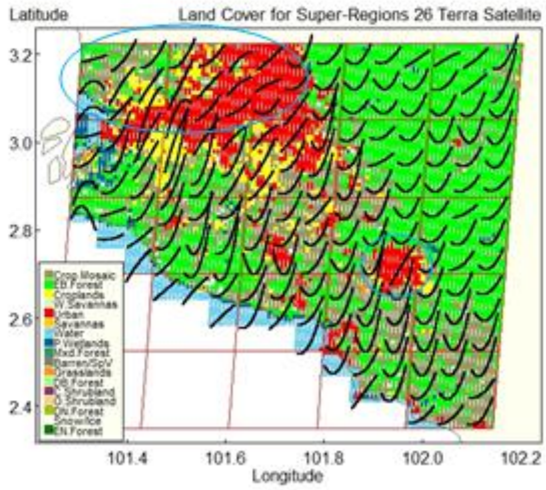
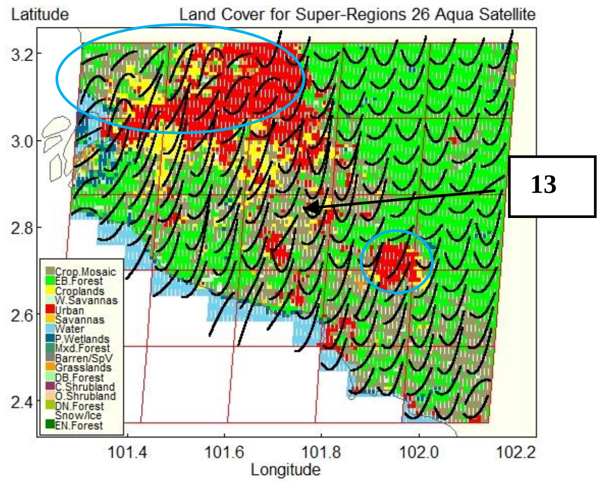


Fig. 9. Map for super region 26



(a)



(b)

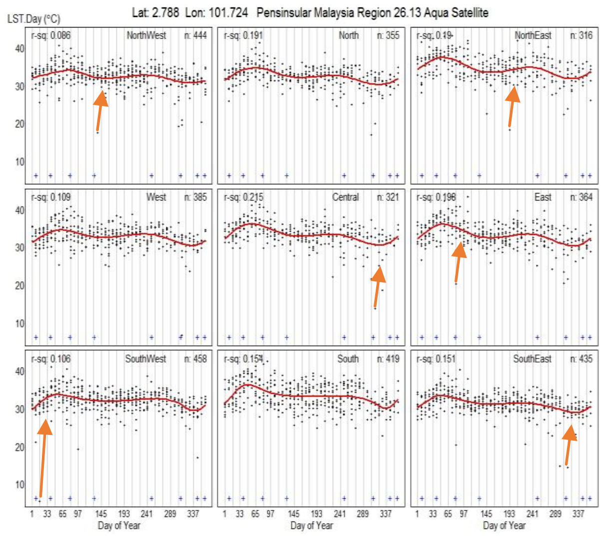


Fig. 10. (a) (b) LST trend with different land cover types between Terra and Aqua satellite for super region 26.

▪ *Seasonal Variation of LST for Terra and Aqua using Cubic Spline Regression Model*

In this section, sub region 13 is chosen from super region 26.

For furher discussion, this subregion consists mainly of crop mosaic, urban and croplands at several areas. The results of the seasonal variation of LST are shown in Fig. 10 and 11 for both satellites for subregion 13.

In Fig. 10, Terra satellite shows LST data vary substantially over short periods especially for eight day data point 81 to 89 (early April) at North East domain and data point 233 to 241 (end of August) at East domain. For example, change in LST values around 15 °C on one day are seen to jump to much higher values approximately around 30 °C within just eight days (indicated by arrow in the graph). These changes may be due to the South West monsoon which started on April to November. By referring to Fig. 9, this area is mainly covered by crop mosaic.

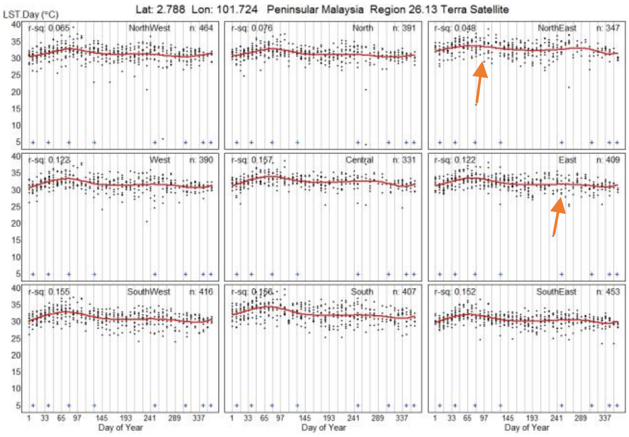


Fig. 11. Annual eight-day seasonal pattern for LST using Terra satellite.

By comparing to Aqua satellite in Fig. 11, the seasonal LST trend is quite similar for all domains. The largest gap of LST data on one day to eigth-day occur at day 17 to 25 (early January) at South West domain (as mentioned by arrow in the graph) with the values from 5 °C - 28 °C. The high gap also found with the values from 15 °C - 30 °C during the South West monsoon season for the other five domains.

The r^2 values also show there is not much difference in r values between the domains, hence this implies that the proposed model has the same performance for all the domains.

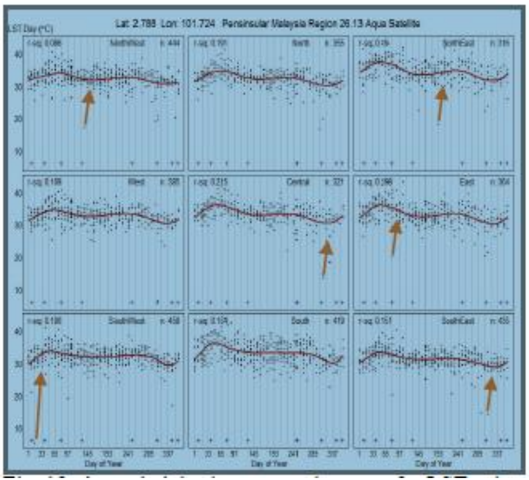


Fig. 12. Annual eight-day seasonal pattern for LST using Aqua satellite.

- *Seasonally-adjusted of Terra and Aqua values with fitted model after adjusting for autocorrelation*

Fig. 12 and 13 show LST trend after they have been seasonally adjusted using cubic spline regression models from 2003 to 2016. Based on these figures, the graph in the bottom right show there are not much change in LST which almost all the domain show uniformly increased in the trend across the year. However, the highest LST is consistently occur at NE domain for Aqua satellite with an upward trend but for Terra satellite this domain show a linear trend. Another linear trend in LST also exists at C domain for Aqua satellite. On the other hand, the lowest LST is consistently occur at SE domain for both satellites.

Futhermore, in Fig. 12 for Terra satellite, six out of nine domains have p-values < 0.05 which are NW, W, E, SW, S and SE while in Fig. 13 in Aqua satellite, three out of nine domains have p-values < 0.05 which are NW, SW ans S. Therefore, it can be concluded that there is significant difference in the changes in LST across the year. This will showed that the curve is more gradient compare to the others. The other domain which have p-values > 0.05 implies there are no different in the changes of LST acrross the year. In addition, S has the highest changes of LST for both satellites which are 2.448 and 2.573 respectively whereas lowest changes of LST was found at difference domain for both satellites which NE has the values of 0.122 for Terra satellite and C has the values of 0.155 for Aqua satellite.

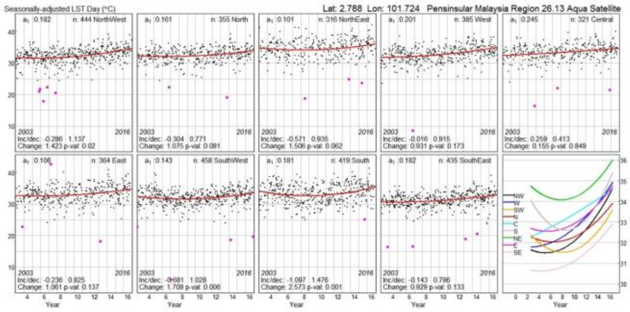


Fig. 13. LST trends (allowing for autocorrelation) after they have been seasonally adjusted using cubic spline regression from Aqua satellite (sub region 13)

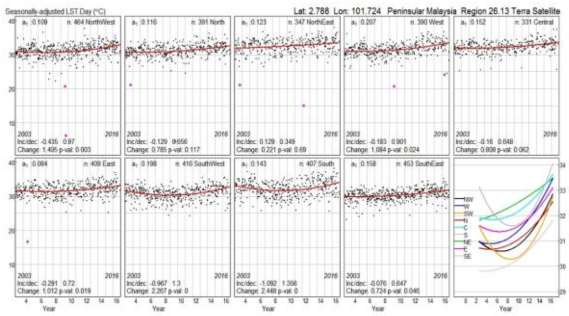


Fig. 14. LST trends (allowing for autocorrelation) after they have been seasonally adjusted using cubic spline regression from Aqua satellite (sub region 13).

V. CONCLUSION

In this paper, the pattern of eight day daytime LST data from MODIS has been compared over Peninsular Malaysia for the period 2003-2016. The method of cubic spline function with the annual periodic boundary condition and weighted least square (WLS) regression implying that this model have consistent of LST performance throughout the years for the nine domain covered. The combination of land types such as crop mosaic, cropland and urban shows that there is no particular trend while forest area showed the same LST trend. However, we found that seasonal variation such as NE and SW and the location of the area of study place an important role in the changes of the LST. The two kinds of satellite have been compared and the results showed similar trend for most of the places even though they operated at different time. We can therefore infer that LST reported in the morning (Terra satellite) is more stable, less spread and less variation than in the afternoon (recorded by Aqua satellite). Therefore, we predict that in the morning the LST will be less volatile than in the afternoon. Furthermore, the results of LST show that 2016 was the highest values of LST. This finding is parallel to the NOAA and MMD's annual report stating that this year was the warmest year compared to the other years. This study is also relevant to commercial farmers or agriculture as they can use LST results to address their future planning according to trend and types of land cover for their future planning in overcoming any crop problems taking into account the monsoon seasons.

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