Statistical Modeling for Land Surface Temperature in Borneo Island from 2000-2019

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Research Article

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Abstract

Increased temperature is one of the signals of global warming. Trends in land surface temperature can be used to measure climate change. This research aimed to investigate the variation of land surface temperature in Borneo island using a cubic spline method and a multivariate regression model. The island was divided into 8 regions each comprising 9 subregions. Land surface temperatures for each subregion from 2000 to 2019 was obtained from the National Aeronautics and Space Administration moderate resolution imaging spectroradiometer database. The average increase in temperature was 0.2^{o}C per decade with a 95% confidence interval of (0.14, 0.27). The changes differed by region; a significant increase was seen in Sarawak, North Kalimantan, West Kalimantan, West-central Kalimantan, Central-east Kalimantan region, a slight decrease in Sabah and Brunei Darussalam (Sabah & Brunei) region, a slight increase in East Kalimantan and a stable trend in South Kalimantan.

1. Introduction

The world is currently facing many environmental issues including global warming. Rising temperatures is one of the signals of global warming. Land surface temperatures (LST) can provide an overview of climate change on a regional and global scale (Zhang and Liang 2018). Climate change can result in damage to human society and the environment (Trenberth 2018) and is predicted to influence public health due to heatwaves, vector-borne diseases such as malaria, respiratory illness (Coleman and Frieman 2014), food resource deficiency, and other human health problems (Bell and Greenberg 2018). In the long term, these problems will have an impact on social and economic aspects globally (Tol 2018).

Many countries around the world are starting to pay attention to the climate change. An increase in LST in an area becomes an important indicator to determine certain policies related to climate change (Fox et al. 2019). Shanghai city as the biggest city in China with massive development with large changes in land use or land cover. This situation has changed the land surface characteristic and spatiotemporal pattern of urban heat island which is designated by LST (Li et al. 2012). Some parts of Southeast Asia such as Kalimantan in Indonesia, East Malaysia and Brunei Darussalam have experienced land-use changes, mainly for oil palm cultivation (Gunarso et al. 2013). Countries in Southeast Asia are facing LST issues as a result of development policies. The average LST increases in Malaysia during 1990–2015 were between 25.39 °C to 32.74 °C and in Indonesia during 1989–2018 were between 26.61 °C to 27.60 °C (Himayah et al. 2019; Hua and Ping 2018). In other Southeast Asian countries, such as Thailand, the mean daily maximum temperature, is predicted to increase by 1.2 to 1.9 °C by 2050 (Marks 2011).

Kalimantan Island is the third largest island after Greenland and New Guinea (Heritage 2020). Most of the islands belong to Indonesia and the remaining islands belong to Malaysia and Brunei Darussalam. Kalimantan has lowlands, mountains, and savanna with a rich variety of plants and animals as a normal habitat in tropical rain forests (Cleary and Lian 1991). Extreme temperatures can cause loss of suitable habitats for animals and plants (Hughes 2017; Kottawa-Arachchi and Wijeratne 2017). Borneo means surface temperatures was predicted to increase by 3–5 °C (Tangang et al. 2012). Some parts of Borneo that were deforested had higher temperatures than forested areas (McAlpine et al. 2018).

Assessing temperature increases based on large-scale satellite imagery data is essential and fundamental for future environmental integrity (Weigand et al. 2019). Several studies have investigated surface temperature trends and patterns using a variety of statistical methods such as cubic splines, which are extensively used for smoothing data (Wongsai et al. 2017) and linear regression (McNeil and Chirtkiatsakul 2016). This study was aimed to investigate the variation of day LST on Borneo island using NASA MODIS data from 2000 to 2019.

2. Materials And Methods

Study Area

Borneo island is in the center of maritime southeast Asia, east of Sumatra, north of Java, and west of Sulawesi. It is located at 109° to 119° east longitude and -4° to 7° south latitude (Fig 1). This study divided Borneo island into 8 regions with each region consisting of 9 subregions. Subregions were defined such that the centers were located at latitudes and longitudes of widths 150 pixels (95 km) apart in order to cover all parts of the island. There were 72 subregions, each one comprising 49 pixels in a 7×7 array.

As shown in Figure 1, region A represents Sabah & Brunei, region B represents Sarawak, region C represents North-Kalimantan, region D represents West-Kalimantan, region E represents East-Kalimantan, region F represents West-central Kalimantan, region G represents Central-east Kalimantan region and region H represents South-Kalimantan.

Data

The MODIS Land Surface Temperature (LST) database, available online, was used in this analysis. The website covers all areas of the world and provides LST data during the daytime and nighttime. The data contains average temperatures every 8 days, clear skies permitting, for areas of size 0.859 km^2 (ORNL DAAC, 2018; Phan et al. 2008). A sinusoidal projection with tiles of size 10×10 latitude degrees was used to ensure area equality of all pixels, with each tile in turn divided into 1200×1200 pixels. The downloaded LST data was based on the center of the subregion on the island to avoid missing data. Missing values were deleted from the analysis. Natural disasters that can cause unexpected transformations of data behavior were excluded. To maintain comprehensiveness of the LST data, all outliers were kept in the data set. Temperature data, originally stored in the Kelvin scale, was converted to the Celsius scale before analyzing.

Methods

A constant seasonal pattern in LST was assumed to be the same for every year. A cubic spline was used to model the continuous seasonal pattern. The model takes the form:

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

where $S(t)$ is the Spline function at time t in Julian calendar, and the defined knots are $t_1 < t_2 < \ldots < t_p$ and $(t - t_k)_+$ is $(t - t_k) > 0$ for $t > x$ and 0 otherwise. $S(t)$ for $t < t_1$ equals $S(t)$ for $t > t_p$ and a, b, c_k are the coefficients of the combination between the linear and cubic spline model.

Selecting the position and the number of knots in the spline is important for smoothing. The LST variation in the different regions in the world can be affected by inter-seasonal variation (Singh, Grover, and Zhan 2014). During the rainy season, the LST will be lower in places that have dry and rainy seasons (Jesus and Santana 2017). Variations in LST may be related to heatwaves in tropical areas (in April and May) and rainfall (in June-September) (Gogoi et al. 2019). LST data in the tropical area will use the time during the rainy and dry season to determine the position of the knots (Lukas et al. 2010; Wongsai et al. 2017). Based on the seasonal characteristics of tropical regions, we chose 8 knots, placing 4 at the beginning of the year and the remaining 4 at the end of the year.

A seasonally adjusted time series was used to minimize the seasonal effect on the LST per day for 18 years using a vector of spline fitted values that we estimated from the cubic splines and the average LST per year in a linear model.

A second order autoregressive model AR(2) was used to fit the LST seasonally adjusted. The model is given by:

$$Y_{at} = \alpha_1 Y_{at-1} + \alpha_2 Y_{at-2} + \varepsilon_t \qquad [3]$$

where Y_{at} is the seasonally adjusted LST at time t, and $Y_{at\text{-}1}$ is the LST at time t-1, t = 1, ..., 365 days, a_1 and a_2 are unknown parameters to be estimated and ε_t is the random error with zero mean and finite variance (Venables and Ripley 2002).

A multivariate regression model (Mardia et al. 1979) was then used to analyse the seasonally adjusted LST data to detect the spatial correlation. The model is given by:

$$Y = XB + U \qquad [4]$$

where Y is the outcome matrix of variables with dimension $n \times m$, n is the number of observations, m is the number of subregions, X is a matrix of independent variables of dimension $n \times q$, where q is the number of independent variables, B is a regression parameter matrix with dimension $q \times m$, and U is an unobserved random disturbance matrix.

All analyses and graphical displays were done using R (R Core Team 2018).

3. Results

Region A was used to describe the Borneo island data and examine the seasonal pattern, shown in Fig. 2. The seasonal pattern for the other 7 regions were investigated using a similar graph.

Figure 2 shows that the average temperatures corresponded to the same day for each of the 19 years. The solid red curves are the fitted natural spline functions with 8 knots, denoted by blue crosses. The curves indicate a modest seasonal pattern with two summer peaks in March and September.

Between 2000 and 2019, the lowest LST corresponded to day 1 (in January), which was during the rainy season, and the highest LST corresponded to day 267 (in September). The highest average of day LST was 28.9^{o}C which occurred in subregion 5 of Region A.

Seasonally-adjusted temperatures were computed by subtracting fitted seasonal patterns and mean-correcting results to obtain the plots shown in Fig. 3. The estimated coefficients of ar_1 and ar_2 from the second order auto-regressive model were very low, indicating that the time series of daily temperatures were independent.

The dashed line in the right panels of Fig. 3 with different scales, compared to the left panels with the black curves, depict that the LST decreased in subregions 3, 5 and 9 and increased in the remaining subregions over the 18 years. The p-values for the linear models (zero knots) with two parameters indicated that only subregions 3 and 9 had a statistically significant increase. The solid curves in the right panel show fitted cubic splines with seven knots with different scales compared to the left panels of red curves with significant p-values for subregions 3, 5 and 9.

Multivariate regression, which adjusts for spatial correlation, was used to estimate the LST increase. In the bottom-right panel of Fig. 3, the mean day LST of (-0.02) was not statistically significant, with a z-value of 0.379 and 95% confidence interval of (-0.12, 0.08)^{o}C per decade.

The increases in LST for each region are shown in Fig. 4. The overall mean increase was 0.2^{o}C per decade. There was a broad variation for each region. The mean change in day LST for Sabah and Brunei (A), Sarawak (B), North Kalimantan (C), West Kalimantan (D), East Kalimantan (E), West Central Kalimantan (F), Central Kalimantan (G), and South Kalimantan (H) regions were − 0.02, 0.24, 0.22, 0.3, 0.1, 0.4, 0.3 and 0.05^{o}C, respectively. All but 3 regions, namely Sabah and Brunei, East Kalimantan, and South Kalimantan regions, had a significant increase in daily LST.

Figure 5 shows the results of LST change for 72 subregions in Borneo using a multivariate regression model. Four colours were used for these 72 subregions signifying the level of increase or decrease in temperatures over the 18 years. The Sabah and Brunei region had a moderate decrease in daily LST, Sarawak, North Kalimantan, West Kalimantan, West-central Kalimantan, and Central-east Kalimantan regions had an increase in LST, while there was a slight increase in East Kalimantan, and LST was likely to be stable in the South Kalimantan.

4. Discussion

The seasonal pattern of the data showed that the highest LST for region 1 occurred on day 267 (in September). A cubic spline method and multivariate regression analysis were used to test seasonal patterns and variations in LST for the 8 regions. The results of the study found that 5 out of the 8 regions had significant increases in daily LST. This study also showed the existence of seasonal patterns. Several studies in Malaysia showed a similar pattern where temperature increases occurred near the end of the year (Ismail et al. 2019). Similar results in areas with four seasons showed that the highest LST appeared during the summer between June-September (Khorchani et al. 2018; Singh et al. 2014).

We found that the average land surface temperatures in Borneo island increased by 0.2^{o}C per decade, or 2^{o}C per century, and was lower than the increase of 3–5 °C per century predicted by Tangang et al. (2012). The change in LST on Borneo island was highly significant. The increase in variation could be an impact of deforestation and land-use change (Wolff et al. 2018).

Changes in land surface temperatures could be influenced by the type of land cover, especially vegetation (Buyadi et al. 2014). Healthy vegetation in an area could be a filter or an absorbent medium thus hindering any increasing surface temperatures. Green vegetation can absorb sunlight radiation and use it for photosynthesis (Babalola and Akinsanola 2016). Temperature increases in Borneo were correspondingly predisposed by deviations in the vegetation of the island (Evans 2020). Deforestation was believed to be a reason for rising temperatures in the landmass area. Other studies have suggested that areas with a low vegetation index would have high LST (Buyadi et al. 2014). Another study showed that the low vegetation index in Borneo illustrates the increase in LST temperatures (Suherman et al. 2014).

One study illustrated that variations in temperature in an area were triggered by changes in land cover produced, for example, by deforestation or reforestation (Prevedello et al. 2019). Previous studies also mentioned that land use land cover change affects LST (Majumder et al. 2018; Odindi et al. 2015; Rasul et al. 2017). If the land cover in an area decreases, the temperature will increase (Parmesan and Hanley 2015). Studies in Borneo have found that interrelated changes in land cover and LST show that both variables are correlated, which could affect human welfare (Wolff et al. 2018). Studies from Malaysia also show that areas with the warmest temperatures are in built-up areas and the coldest areas are located in forest and mangrove areas (Sheikhi and Devi 2018). Other studies have also confirmed that land-use change has a substantive impact on climate change (Scott et al. 2018).

5. Conclusions

The cubic spline model was used to model land surface temperatures on Borneo island. The appropriate number and placement of the knots was determined to obtain a smoother model. The study indicated a statistically significant increase in the average daily land surface temperatures in Borneo for 8 regions. Significant increases in LST were found for Sarawak, West Kalimantan, East Kalimantan, West-central Kalimantan, and Central-east Kalimantan regions. Among the remaining 3 regions, the LST in Sabah & Brunei region slightly decreased, East Kalimantan slightly increased, and in South Kalimantan Regions, the trend was stable.

An increase in LST on Borneo Island is one signal of regional warming. However, further studies are needed to confirm the findings of this study on a wider scale. Other approaches are needed to improve the accuracy and estimation, for example, using other large islands located in latitudes further form the equator, such as Greenland. The addition of other variables such as NDVI, land elevation, and land cover in the analysis may also be important because most large islands contain mountains and land-use change.

Declarations

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Conflict of interest*:* The authors declare that there are no competing interests.

Availability of data and material and code*:* The data that support the findings of this study and the command code are available in *LST Borneo* at *https://drive.google.com/drive/u/0/shared-drives*.

Authors' contributions: Munawar Munawar and Tofan Agung Eka Prasetya obtained the data and performed statistical, Rhysa McNeil and Rohana Jani contributed to statistical analyses, discussion and interpretation of the results. All authors contributed through to writing and editing the manuscript.

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Figures

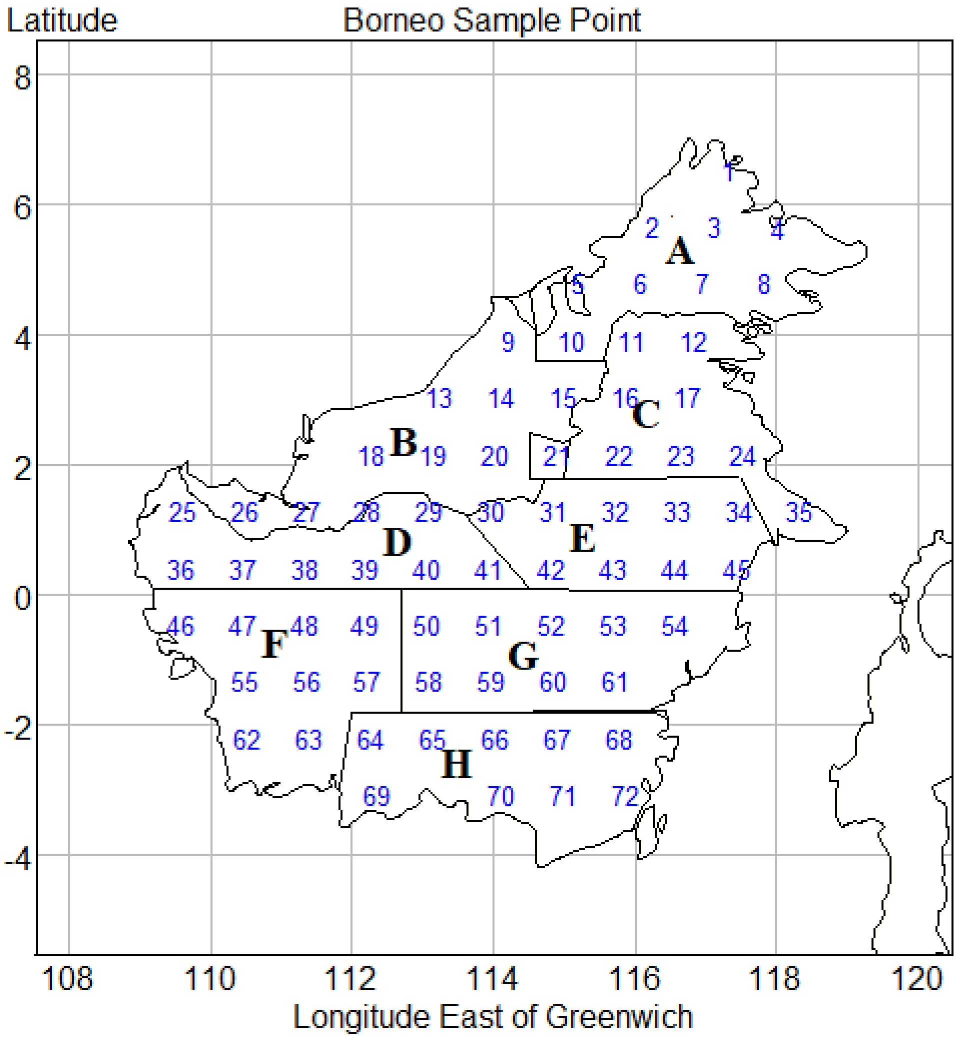

Figure 1

Borneo island, showing the 72 subregions of the study

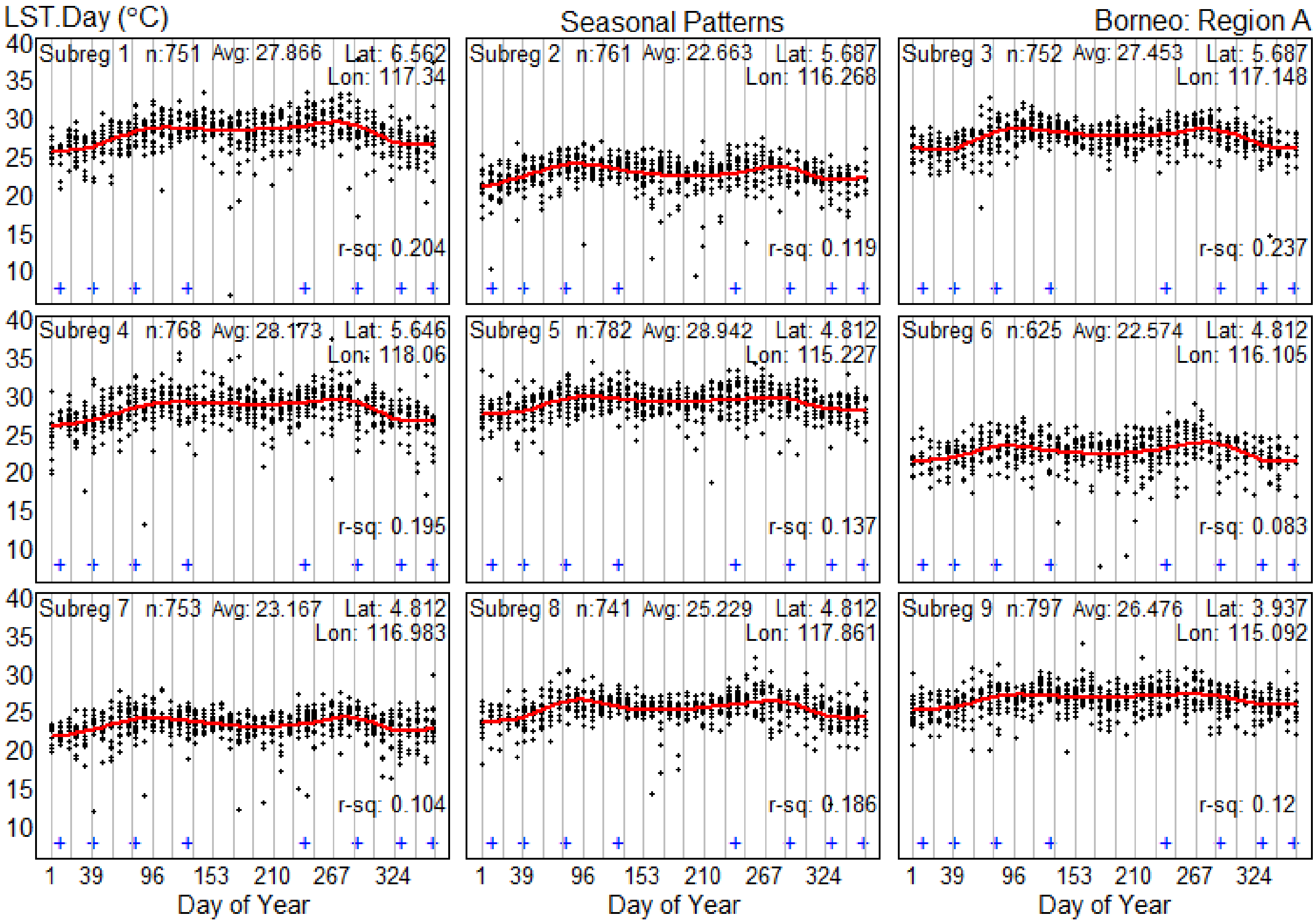

Figure 2

Seasonal pattern of land surface temperatures in Borneo, Region A

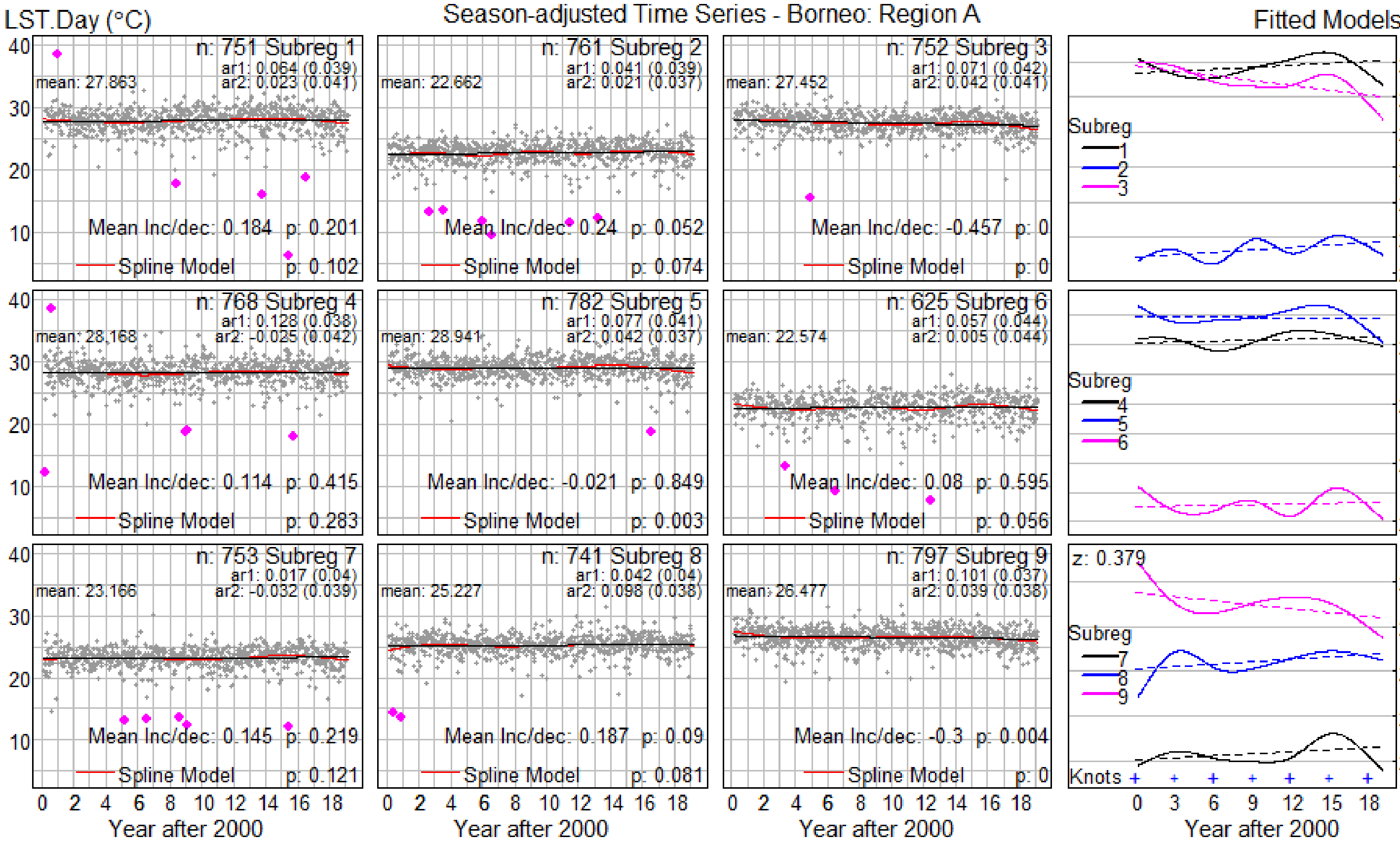

Figure 3

Seasonally-adjusted land surface temperatures for Borneo island, Region A

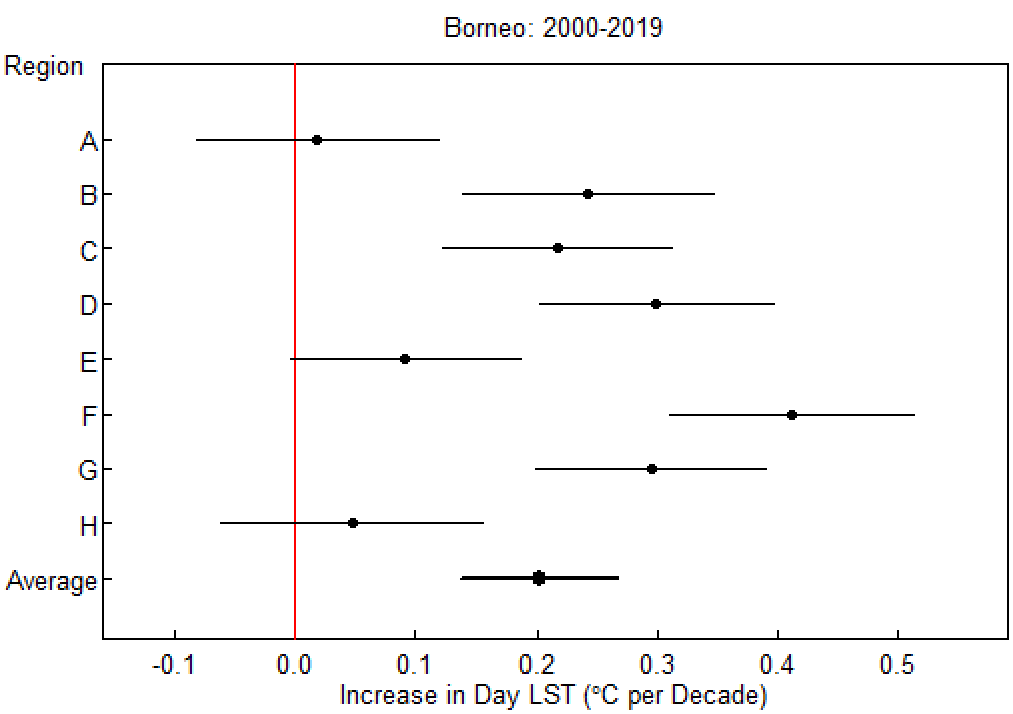

Figure 4

Increase in mean day LST with 95% confidence intervals for Borneo

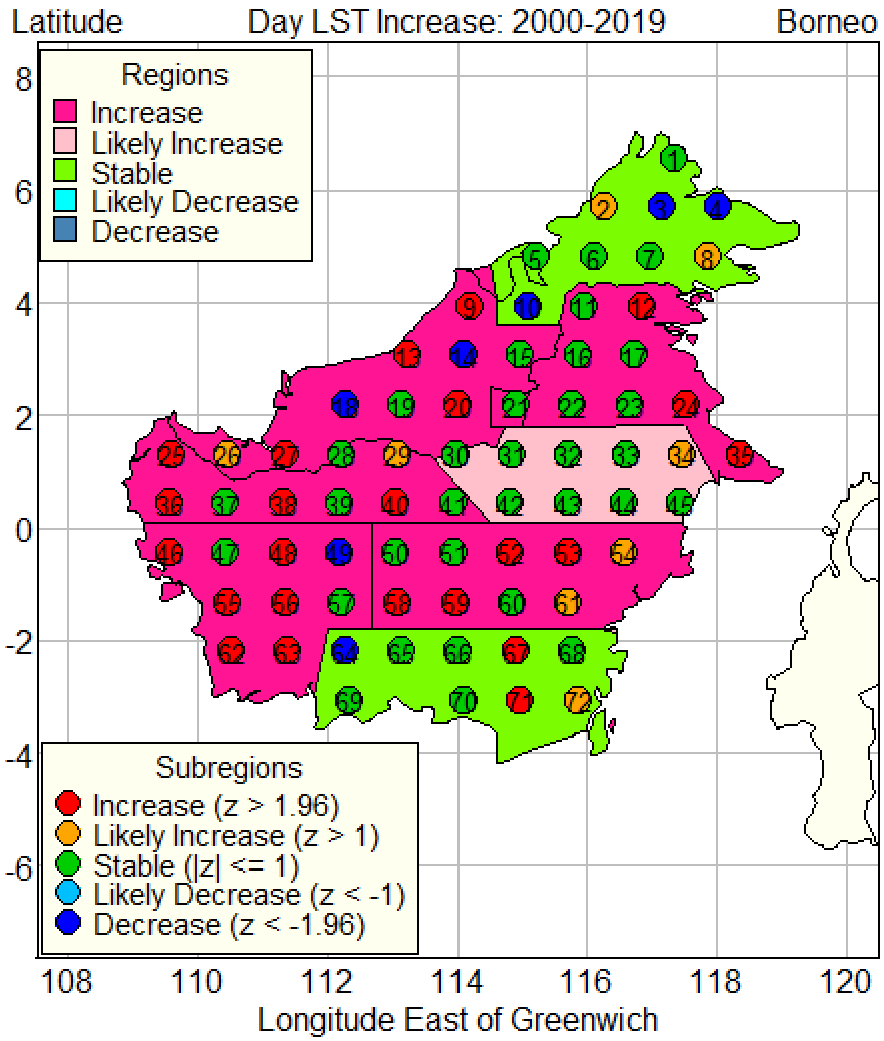

Figure 5

Trends in land surface temperatures for Borneo island, 2000 – 2019 (°C/decade)