Land Surface Temperature Retrieval for Climate Analysis and Association with Climate Data

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Abstract
The aim of this study is to demonstrate the relationship between the long years’ monthly average (LYMA) land surface temperature (LST) and the LYMA air temperature (Ta), the total precipitation (P), and the relative humidity (RH). Data from 27 meteorological stations in the Eastern Thrace region and corresponding thermal infrared images from Landsat-5 (TM) and Landsat-7 (ETM+) were used in this study. Simple regression models were developed for each meteorological station to predict the LYMA Ta, P, and RH based on the LST values. The resulting LST-based prediction models were judged based on the correlation coefficient (r) and root mean square (RMSE). The average correlation and RMSE for the LST-based Ta were r = 0.959 and RMSE = 1.771 °C. The average correlation and RMSE for the LST-based P were r = -0.863 and RMSE = 10.098 mm. The average correlation and RMSE for the LST-based RH were r = -0.932 and RMSE = 1.875%. The results indicate that LST can be a good estimator for LYMA Ta, P, and RH, and LYMA Ta is positively, and LYMA P and LYMA RH are negatively correlated with LYMA LST.

Keywords: climate, remote sensing, Landsat, land surface temperature.

Introduction
Weather is an atmospheric condition over a short time period, on the other hand climate is a long term average of the weather [Sensoy and Tastekin, 2005; EPA, 2013; TSMS, 2013]. Accordingly, weather may vary instantaneously as opposed to the climate that reflects more stability over an extended period of time [EPA, 2013; TSMS, 2013]. Climate includes the potential hazards manifested by extreme weather events [Sensoy and Tastekin, 2005]. Thus, a good knowledge of climate is vital for optimal management and evaluation of many activities including agriculture, natural resources, disaster recovery, urbanization,
transportation, and natural energy [Sensoy and Tastekin, 2005; FAO, 2013]. A big challenge with establishing reliable climate information is related to data availability since meteorological stations may not be present everywhere or in right spatial frequency because of the geographic and economic conditions [Ozelkan et al., 2011]. Remote sensing (RS), on the other hand, provides a great opportunity to reach to those areas without meteorological stations [Ozelkan et al., 2011]. Satellite RS can measure land surface temperature (LST) that is an important parameter of land surface energy budget [Stroppiana et al., 2014] and climate systems to monitor long-term environmental changes [Dash et al., 2002; Guillevic et al., 2012]. Due to its relationship with meteorological parameters, LST has been considered as an important input data in diverse environmental models of land-atmosphere energy exchange, numerical weather forecast, global hydrological cycle, climate change, etc. [Dash et al., 2002, 2003; Cristóbal et al., 2008; Duan et al., 2012]. Previous studies have shown that high correlations are found between LST and meteorological data such as air temperature (T\textsubscript{a}), precipitation total (P\textsubscript{t}) and relative humidity RH [Wan et al., 2004; Karnieli et al., 2010; Tian et al., 2012]. While based on the meteorological relationship, it is a reasonable hypothesis that a good relationship also exists at a climate level, but to our best knowledge there are no studies that used climate data to analyze the relationship of the long years' monthly average (LYMA) LST with LYMA T\textsubscript{a}, LYMA P\textsubscript{t} and LYMA RH. Thus, this study is aimed to close this research gap.

More specifically, the aim of the study is to establish a more reliable climate data estimation using LST. For this purpose, we computed LYMA LST values using a new remote sensing data (RSD) processing system that was created using the C Sharp (C#) programming language that comprises the necessary image processing steps. Note that we have utilized in this study Landsat LST since it has higher spatial resolution compared to the meteorological satellites (such as NOAA-AVHRR, MSG, and Seviri), which have higher temporal resolutions. We aim to produce a high spatial resolution LYMA LST data to associate with the climate data. Accordingly, LYMA T\textsubscript{a}, P\textsubscript{t} and RH climate data from 27 meteorological stations in Eastern Thrace were analyzed along with the LYMA LST climate data of the corresponding stations. The subsequent sections will describe the study area and the findings of this research further.

**Study area**

The Eastern Thrace Region is located in the northwest Turkey between 26° - 29° 2’ eastern longitudes and 40° - 42° 2’ northern latitudes and covers an area of approximately 24,000 km\(^2\) (Fig. 1). In the north, Star Mountains are located parallel to the Black Sea coast that seldom exceeds 1000 m. In the South, Ganos and Kuru Mountains are located with lower altitudes, and the remaining area consists of low hills [TDA, 2012]. The study area is encircled by the Black Sea in the north, the Aegean Sea in the West and the Marmara Sea in the South. Eastern Thrace region has 3 different climates that are known as the Continental, the Black Sea, and the Marmara climates [Sensoy et al., 2008]. Hot and dry summers and cold and rainy winters are the main features of the Continental climate which creates a “dry forests” natural vegetation formation [Sensoy et al., 2008]. Marmara climate can be considered as a transition between the Continental, the Black Sea and the Mediterranean climates. The features for the Marmara climate are: summers are not as rainy as the Black Sea climate and not as dry as the Continental climate, and winters are not as warm as the
Mediterranean climate and not as cold as the Continental Climate [Sensoy et al., 2008]. The northern slopes of mountains and the Black Sea coast of the Marmara region have the Black Sea climate. The most significant difference of the Black Sea climate from the others is the occurrence of low $T_a$ differences between summers and winters. While all seasons are rainy, summers are cool, winters are mild and warm in the coastal region, the higher altitudes are snowy and cold in winters [Sensoy et al., 2008].

Data
In order to reflect the long-years’ average climate data in the best way possible, data of active as well as inactive meteorological stations with at least 10 years (since 1970) of $T_a$, $P_t$ and RH data in the Eastern Thrace region were used in this study (Tab. 1). Total number of stations is 27, and 13 of them are still actively functioning. Figure 1 shows the distribution of the stations in the Eastern Thrace region.
Table 1 – Locations and data availability of meteorological stations in the study area.

| Station ID | Latitude (m) (N) | Longitude (m) (E) | Condition | Functioning Era |
|------------|------------------|-------------------|-----------|-----------------|
| 0          | 541749           | 4534220           | Active    | 1970 - present  |
| 1          | 567668           | 4557650           | Passive   | 1975 - 2006     |
| 2          | 583608           | 4571000           | Passive   | 1984 - 1997     |
| 3          | 509863           | 4496200           | Active    | 1972 - present  |
| 4          | 539903           | 4535790           | Active    | 2000 - present  |
| 5          | 529532           | 4547730           | Active    | 2002 - present  |
| 6          | 581519           | 4636370           | Passive   | 1976 - 1994     |
| 7          | 563645           | 4630420           | Passive   | 1970 - 1980     |
| 8          | 543194           | 4608080           | Passive   | 1970 - 2005     |
| 9          | 520568           | 4501830           | Passive   | 1972 - 1993     |
| 10         | 580352           | 4536420           | Passive   | 1987 - 1997     |
| 11         | 508579           | 4540580           | Passive   | 1987 - 1998     |
| 12         | 542318           | 4557910           | Passive   | 1970 - 1991     |
| 13         | 621554           | 4553660           | Passive   | 1984 - 1997     |
| 14         | 445911           | 4551550           | Passive   | 1984 - 1997     |
| 15         | 508987           | 4562980           | Passive   | 1970 - 1989     |
| 16         | 484953           | 4563180           | Passive   | 1987 - 1996     |
| 17         | 591238           | 4609940           | Passive   | 1985 - 1997     |
| 18         | 518119           | 4620730           | Active    | 1970 - present  |
| 19         | 462610           | 4613980           | Active    | 1970 - present  |
| 20         | 576425           | 4554380           | Active    | 1970 - present  |
| 21         | 447762           | 4529790           | Active    | 1970 - present  |
| 22         | 525944           | 4577780           | Active    | 1970 - present  |
| 23         | 492246           | 4526260           | Active    | 1980 - present  |
| 24         | 577013           | 4568130           | Active    | 1970 - present  |
| 25         | 473741           | 4567100           | Active    | 1970 - present  |
| 26         | 613509           | 4577490           | Active    | 1970 - present  |

In this study, originally 60 to 120 m spatial resolution Landsat-5 (TM) and Landsat-7 (ETM+) thermal satellite images were used. The study area could be covered by two (top and bottom) Landsat images. The Landsat coverage of the Eastern Thrace region is shown in Figure 1. 432 satellite images (202 of them are Landsat - 5 (TM) satellite images and 230 of them are Landsat - 7 (ETM+)) were acquired between January 2000 and January 2012. The thermal infrared bands of Landsat - 5 (TM) (6th band) and Landsat - 7 (ETM+) (6.1th band) were used for LST generation [USGS, 2012]. 30 m spatial resolution proposed by the United States Geological Survey (USGS) was accepted for LST images [USGS, 2012]. All data sets were registered into Universal Transverse Mercator projection system with WGS 84 datum (UTM-WGS84) and zone 35, north. The number of available LST images for months 1 through 12 is 9, 17, 33, 40, 45, 56, 71, 59, 47, 35, 10, and 10, respectively. Note that the number of the images presented by USGS and selected for our study varies significantly depending on the cloud conditions.

**Methodology**

In this section, we will present the detailed methodology, including RSD processing, association of LST with meteorological data and RSD processing system.
Remote sensing data processing

The thermal infrared band (6th band) of Landsat satellite images are used to generate the LST images. Sequence of operations are as follows: thermal infrared bands 1) were converted from digital number (DN) to at sensor radiance $L_{\lambda}$ using equation [1], 2) were atmospherically corrected using the radiative transfer equation (RTE) to convert the sensor radiance to surface radiance using equation [2], and 3) was converted from radiance to surface brightness temperature (T) (Kelvin) (or sensor T skipping the equation [2]) using equation [3] given below [Chander et al., 2009; Fornaciai et al., 2009; Coll et al., 2010; YCEO, 2010; NASA, 2011; Tarantino, 2012]. Celsius (°C) T values were generated by subtracting 273.15 from Kelvin values.1]

$$L_{\lambda} = \left( \frac{\text{LMAX}_{\lambda} - \text{LMIN}_{\lambda}}{\text{QCALMAX} - \text{QCALMIN}} \right) (QCAL - QCALMIN) + LMIN_{\lambda} \quad [1]$$

Where $L_{\lambda}$ is the cell value as sensor radiance - (Wm$^{-2}$sr$^{-1}$μm$^{-1}$), $QCAL$ is quantized calibrated pixel value - (DN), $\text{LMIN}_{\lambda}$ is spectral radiance scales to $QCALMIN$ - (Wm$^{-2}$sr$^{-1}$μm$^{-1}$). $\text{LMAX}_{\lambda}$ is spectral radiance scales to $QCALMAX$ - (Wm$^{-2}$sr$^{-1}$μm$^{-1}$), $QCALMIN$ is the minimum quantized calibrated pixel value (typically = 1) - (DN), and $QCALMAX$ is the maximum quantized calibrated pixel value (typically = 255) - (DN).

The sensor radiance (i.e. top of the atmosphere radiance) is the mixing result of absorptions and emissions along the path between Earth-surface to sensor [Chander et al., 2009]. For converting sensor radiance to surface-leaving radiance, input parameters (transmittance, upwelling radiance and downwelling radiance) that occur along the path needed for atmospheric correction of Landsat data were acquired from resources published NASA web-based tool Atmospheric Correction Parameter Calculator [Barsi et al., 2003; Coll et al., 2010]. Transmittance, upwelling radiance and downwelling radiance values (Tab. 2) of selected images for testing the atmospheric correction computation were used to compute surface-leaving radiance using RTE as shown below.

$$L_{\lambda, atc} = \frac{1}{\varepsilon} \left( \frac{L_{\lambda} - L_{\uparrow}}{\tau} - \frac{1 - \varepsilon}{L_{\downarrow}} \right) \quad [2]$$

Where $L_{\lambda, atc}$ is the atmospherically corrected cell value as radiance - (Wm$^{-2}$sr$^{-1}$μm$^{-1}$), $L_{\lambda}$ is the cell value as radiance - (Wm$^{-2}$sr$^{-1}$μm$^{-1}$), $L_{\uparrow}$ is upwelling radiance - (Wm$^{-2}$sr$^{-1}$μm$^{-1}$), $L_{\downarrow}$ is downwelling radiance - (Wm$^{-2}$sr$^{-1}$μm$^{-1}$), $\tau$ is transmittance of atmosphere (unitless), and $\varepsilon$ is surface emissivity – (typically = 0.95).

| Date          | $\tau$ | $L_{\uparrow}$ (Wm$^{-2}$sr$^{-1}$μm$^{-1}$) | $L_{\downarrow}$ (Wm$^{-2}$sr$^{-1}$μm$^{-1}$) |
|---------------|--------|-------------------------------------------|-----------------------------------------------|
| 19.02.2010    | 0.82   | 1.20                                      | 1.96                                          |
| 26.05.2010    | 0.73   | 2.02                                      | 3.23                                          |
| 13.07.2010    | 0.57   | 3.39                                      | 5.15                                          |
| 15.09.2010    | 0.70   | 2.23                                      | 3.53                                          |
After, $L_{\lambda\, atc}$ (or use $L_{\lambda}$, if equation [2] is not necessary to apply) is transformed to $T$ of the monitored Earth-atmosphere system as a more useful and comparable physical data [NASA, 2011]. Radiance balance and transfer is under the control of $\varepsilon$ and the prelaunch calibration constants used to obtain the $T$ using the inverse of Planck function as shown below [Gangopadhyay et al., 2006; Chander et al., 2009; Fornaciai et al., 2009; Coll et al., 2010; YCEO, 2010; NASA, 2011; Tarantino, 2012].

$$T = \frac{K_2}{ln(K_1\varepsilon / L_{\lambda}) + 1} \quad [3]$$

where $T$ is surface brightness $T$, if equation [2] is applied - (Kelvin), $T$ is satellite brightness $T$, if equation [2] is not applied - (Kelvin), $K_1$ calibration constant = 607.76 and 666.09 for Landsat 5 and 7 respectively ($\text{Wm}^{-2}\text{sr}^{-1}\mu\text{m}^{-1}$), $K_2$ calibration constant = 1260.56 and 1282.71 for Landsat 5 and 7 respectively (Kelvin), and $\varepsilon$ is surface emissivity (assumed as 0.95 for atmospherically uncorrected data and 1 for corrected data).

We would like to briefly elaborate on the selection of a constant $\varepsilon$: It is well known that natural surfaces generally have an $\varepsilon$ of about 0.95–0.98 in the thermal wavelength [Qin et al. 2001; Jin and Liang, 2006]. On the other hand, according to the literature $\varepsilon$ of the most land cover classes is close to 0.95 [see e.g. Arnfield 1982; Voogt 2000; Hewison, 2001; Jin and Liang, 2006]. If the spectral $\varepsilon$ is 1, Earth’s surface is a black body [Chander et al., 2009], therefore $\varepsilon = 1$ is used for corrected data in equation [3] [YCEO, 2010].

For the analysis of the atmospheric correction effect, Landsat-5 (TM) satellite LST data and $T_a$ data from 13 meteorological stations (which were active as of 2010) on 4 different dates and seasons were used for testing. Two LST computation procedures were tested: Procedure 1: reflects the LST computation without atmospheric correction, where the computation was done in the order of DN to $L_{\lambda}$ conversion [equation 1], and radiance to satellite brightness $T$ conversion [equation 3], and Procedure 2: reflects the LST computation with atmospheric correction, where the computation was done in the order of conversion $L_{\lambda\, atc}$ [equation 2] and radiance to surface brightness $T$ conversion [equation 3], Procedure 3: indicates meteorological station $T_a$ ($^\circ\text{C}$) data. The results that are presented in Table 3 include used data type (LST versus $T_a$), data acquisition date, applied data computation procedure for LST (Procedure 1: uncorrected or Procedure 2: corrected) and station ID numbers.

The Pearson correlation coefficient ($r$), significance probability ($p$), average (Avg.) and standard deviation (Std.) results between LST procedure 1 and $T_a$, LST procedure 2 and $T_a$ and LST procedures 1 and 2 are given in Table 4. Examining the correlation of the 2 output data sets from procedures 1 and 2 with the meteorological station data sets, it was observed that both LST procedure results were highly correlated with $T_a$ with $r$ varying between 0.86 to 0.98 for LST procedure 1 and 0.71 to 0.99 for LST procedure 2, and similarly, significance $p$ varying between 0.02 to 0.14 for LST procedure 1 and 0.01 to 0.29 for LST procedure 2. While the atmospheric correction (procedure 2) generated slightly better results compared to the uncorrected data (procedure 1) in most cases (11 out of 13 stations), the Avg. performance for LST procedures 1 and 2 were very close ($r = 0.942$
and 0.949) but the variability of LST procedure 1 (Std. = 0.04) was less than the variability of LST procedure 2 (Std. = 0.08), which showed that LST procedure 1 is slightly more robust. Further correlation analysis and p values between the LST procedures 1 and 2 indicated that the LST procedure 1 and 2 results are statistically indifferent.

### Table 3 - Atmospherically corrected and uncorrected LYMA LST and LYMA $T_a$ data and for selected stations (Proc*=Procedure).

| Station ID | Data Date | Proc* | 0 | 3 | 4 | 5 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 |
|------------|-----------|-------|---|---|---|---|----|----|----|----|----|----|----|----|----|
| LST        | 15.9.2010 | 1     | 27.02 | 20.36 | 28.34 | 29.64 | 30.07 | 30.18 | 20.70 | 31.36 | 21.60 | 29.64 | 29.21 | 22.53 |
| LST        | 13.7.2010 | 1     | 29.21 | 25.02 | 31.79 | 30.94 | 31.36 | 32.64 | 33.06 | 25.80 | 30.08 | 26.10 | 33.50 | 33.90 |
| LST        | 26.5.2010 | 1     | 28.77 | 21.99 | 35.57 | 32.63 | 33.48 | 35.15 | 31.36 | 21.40 | 32.64 | 23.80 | 33.50 | 32.64 |
| LST        | 19.2.2010 | 1     | 16.91 | 12.00 | 17.86 | 18.34 | 14.98 | 14.98 | 18.34 | 12.20 | 16.43 | 12.50 | 17.39 | 16.91 |
| LST        | 15.9.2010 | 2     | 30.24 | 32.49 | 32.07 | 33.88 | 33.28 | 34.48 | 34.48 | 32.49 | 36.26 | 33.77 | 33.88 | 33.28 |
| LST        | 13.7.2010 | 2     | 34.14 | 37.79 | 38.47 | 30.04 | 37.76 | 39.89 | 40.59 | 39.80 | 35.60 | 38.48 | 41.30 | 41.99 |
| LST        | 26.5.2010 | 2     | 31.94 | 35.68 | 40.96 | 32.07 | 33.88 | 33.28 | 34.48 | 32.49 | 36.26 | 33.77 | 33.88 | 33.28 |
| LST        | 19.2.2010 | 2     | 17.80 | 15.61 | 18.95 | 19.53 | 15.45 | 15.45 | 19.53 | 17.40 | 17.22 | 10.70 | 18.38 | 17.80 |
| T_a        | 15.9.2010 | 3     | 21.20 | 28.14 | 19.77 | 20.26 | 21.20 | 22.20 | 19.90 | 28.14 | 19.80 | 29.02 | 19.20 | 20.50 |
| T_a        | 13.7.2010 | 3     | 25.60 | 32.04 | 19.77 | 20.26 | 21.20 | 22.20 | 19.90 | 28.14 | 19.80 | 29.02 | 19.20 | 20.50 |
| T_a        | 26.5.2010 | 3     | 20.40 | 33.31 | 19.77 | 20.26 | 21.20 | 22.20 | 19.90 | 28.14 | 19.80 | 29.02 | 19.20 | 20.50 |
| T_a        | 19.2.2010 | 3     | 11.10 | 15.19 | 7.78  | 10.75 | 11.40 | 11.50 | 11.00 | 16.64 | 11.30 | 11.21 | 11.60 | 12.30 |

One particular remark can be made related to station 5, where a huge correlation decrease (0.18) was observed due to atmospheric correction. Further analysis indicated that the station 5 and its neighborhood were more hazy during the image acquisition dates. Also station 26 was another location where atmospheric correction resulted in slightly worse
results. This can be explained since the station is located in the middle of the forest. The vision was clearer in the area of the other stations.

Our above findings seem to align well with the literature. Song et al. [2001] indicated that atmospheric correction eliminates the effect of the atmosphere for better land cover analysis and classification. On the other hand atmospheric correction does not provide much more accurate results and not always necessary except multitemporal land cover change detection analysis of a certain region. LST is highly related to the combination of all meteorological, land surface and geographic parameters [Göttsche and Olesen, 2001; Duan et al., 2012] that are decisive in climate (i.e. atmosphere) formation [Meehl et al., 2003]. In our study, the land cover determination is not important; the aim is to find the correlation between LYMA climate data and LST that should include all effects of atmospheric variations for expressing climate seasonal changes better. Based on the above results and analysis (same average performance of LST Procedures 1 and 2 and slightly more robust outputs of the LST procedure 1), here we have decided to use LST Procedure 1. A benefit of excluding atmospheric correction was a decrease in processing times due to the exclusion of the related processing steps.

**Determination of relation of meteorological data with LST and filter size to be used**

The determination of the LST identification field (filter size to be applied) that best expresses the domain of a meteorological station is important to find the most correlated filter size of LST with meteorological station’s data. Initially for this purpose, LST values corresponding to the meteorological stations’ coordinates (direct pixel values of LST) were computed. Furthermore, 3x3 and 5x5 mean filters were performed on the meteorological stations’ coordinates. Finally, the computations of LYMA LST values were generated. The correlation between climate data and LST values, were examined to determine the highest correlated ones. Tables 5a-5b and Figures 2a-2b show as an example, the analysis results of RSD and climate data of the meteorological stations 0 and 25. As seen under the LST column (Tab. 5) stable correlation relationships were observed with direct pixel values of LST, for example high correlations were found in station 0, conversely low correlations were found in station 14. While not shown here to keep the presentation concise, similar instability in correlation was observed across all stations. Pixel values of the 3x3 and 5x5 mean filter results were relatively close but found to be much more stable. However analysis of all 27 stations one at a time showed that 5x5 mean filter generated slightly better results for the LYMA \( T_a \), \( P_t \) and RH estimation. As a result, 5x5 mean filter was selected for the purposes of LST computations. The results for stations 0 and 25 (presented in Tabs. 5a-5b and simple linear regression plots shown in Figs. 2a-2b) show that the variance explained \( (r^2) \) for the long years 5x5 mean filtered LST data with LYMA \( T_a \), \( P_t \) and RH exceeds 0.74. Again results for remaining stations (not shown) indicate similar relationships.

**Remote sensing data processing system**

The study area (working frame) was decided to be in the boundary in the UTM coordinates: upper left corner (4668045 m, 410895 m) and lower right corner (4428615 m, 636645 m). For the system of processing, UTM-WGS84 zone 35 north projection system and a 30 m spatial resolution were selected. C# programming language was used to build the system on a MS Windows platform. Some of the reasons for selecting C# were associated with the
advantages of such as speed of processing, less memory usage and parallelization capability [Fourment and Gillings, 2008].

For each pixel in each image, the designed system processed 432 Landsat images and computed the corresponding LST values. From the archived Landsat 5 and 7 images, LYMA of LST was computed. All images were separately taken into consideration for each month where the average LST of that month was computed to obtain LYMA. The processing steps are briefly summarized below:

I) For a selected month,
   For bands 6 and 6.1:
   a) Read the metadata (MTL) file of each corresponding Landsat image to extract specific information; such as the date of acquisition, the image type, the corner coordinates, and all other parameters that are used in the described equations;
   b) Apply a 5x5 mean filter to the consisting LST frames;
   c) Incorporate the 5x5 mean filtered LST frames into the LYMA LST frame of the

Figure 2 - LYMA LST and LYMA T, P, RH relation for Stations 0 (a) and 25 (b) using simple linear regression.
corresponding month;
d) Continue process described above until no more images are left in that corresponding month.

II) Calculate and store LYMA LST frame of each pixel into separate files;
III) Calculate LYMA LST, processing all archived images.
IV) Select the next month for the same process above to the end of the 12th month data.

Table 5 - Correlation analysis for LYMA LST and climate data.

| Month | $T_a$ | $P_t$ | RH | LST | LST(3x3) | LST(5x5) |
|-------|-------|-------|-----|-----|----------|----------|
| 1     | 4.90  | 60.40 | 83.10 | 8.10 | 8.01     | 7.91     |
| 2     | 5.10  | 55.13 | 80.80 | 9.38 | 9.31     | 9.16     |
| 3     | 7.40  | 55.09 | 80.50 | 14.19 | 13.98   | 13.11    |
| 4     | 11.90 | 41.95 | 78.50 | 18.53 | 18.32   | 18.00    |
| 5     | 16.70 | 38.35 | 76.80 | 26.16 | 26.04   | 25.83    |
| 6     | 21.40 | 36.38 | 73.50 | 28.22 | 28.04   | 27.83    |
| 7     | 23.80 | 24.46 | 70.60 | 30.53 | 30.37   | 30.12    |
| 8     | 23.60 | 15.00 | 71.70 | 31.48 | 31.29   | 31.09    |
| 9     | 19.90 | 37.70 | 75.00 | 27.48 | 27.45   | 26.38    |
| 10    | 15.30 | 65.21 | 79.30 | 18.24 | 18.24   | 17.78    |
| 11    | 10.50 | 70.95 | 82.30 | 11.02 | 10.96   | 10.90    |
| 12    | 7.00  | 74.12 | 82.70 | 2.48  | 2.46    | 4.24     |

$r$ between $T_a$ and LST: 0.946, 0.947, 0.959
$r$ between $P_t$ and LST: -0.901, -0.900, -0.903
$r$ between RH and LST: -0.950, -0.950, -0.959

Results
As illustrated for stations 0 and 25 in Figure 2, simple regression models were developed for each meteorological station to predict the LYMA $T_a$, $P_t$ and RH based on the LST values. The resulting LST-based prediction models were judged based on the correlation
coefficient and root mean square (RMSE). The results for all stations are summarized in Table 6. Minimum LST and $T_a$ correlation was observed at station 17 with $r = 0.923$, $r^2 = 0.852$, RMSE = 2.186 °C and maximum correlation was observed at station 16 with $r = 0.992$, $r^2 = 0.984$, RMSE = 0.998 °C. Minimum LST and RH correlation was observed at station 26 with $r = -0.779$, $r^2 = 0.607$, RMSE = 1.859 % and maximum correlation was observed at station 25 with $r = 0.976$, $r^2 = 0.953$, RMSE = 1.565 %. Minimum LST and $P_t$ correlation was observed at station 8 with $r = -0.760$, $r^2 = 0.578$, RMSE = 9.904 mm and maximum correlation was observed at station 26 with $r = 0.909$, $r^2 = 0.827$, RMSE = 8.760 mm. As seen in the Table 6, positive correlation ($r$) was found between LYMA $T_a$ and LYMA LST; conversely LYMA $P_t$ and LYMA RH were negatively correlated with LYMA LST. Also, the previous studies indicated that positive correlation was found between LST and $T$, on the other hand LST was found to be negatively correlated with $P_t$ and RH [Wan et al., 2004; Karnieli et al., 2010]. This similar knowledge, which is based on studies that use a small amount of data set, strengthens our study that indicates that LYMA LST may be used as climate data.

The correlation and RMSE results show that for the study region, LYMA LST is more appropriate to determine LYMA $T_a$, then comes LYMA RH and then LYMA $P_t$. These relations can be explained as follows: LST and $T_a$ are in the same unit and associated with the first-order, thus the correlation between them is the highest. RH is negatively correlated with $T_a$ in isobaric heating condition, where evaporation, evapotranspiration, vapor pressure and etc. may change [TSMS, 2005], thus $T_a$ (i.e. LST) and RH may be defined as associated with second-degree. Formation of $P_t$ is slightly more complex than the others. According to hydrological cycle, $P_t$ does not remain constant where the event occurred. Some of the $P_t$ move across the land, some of them flow into ground, some of them become soil moisture and ground water, which may reoccur as a fresh water source, some of them evaporate, some of them are captured by vegetation and then evapotranspiration and etc. [Jones et al., 2010; USGS, 2013]. According to the complex structure described above, compared to others, lowest correlation was occurred between LST and $P_t$ may be defined as associated with third-degree.

**Summary and conclusions**

Optimal management of agriculture, forestry, water resources, disaster, urbanization, transportation and many other activities can be achieved by comprehending an area’s climate conditions. Meteorological measurements may not be able to obtained everywhere because of geographic and economic obstacles that usually hinders climate studies. Climatic interpretations and analysis can be performed by RSD in lack of meteorological stations. LST is a RSD that reflects geographic effects and can be used as an alternative to meteorological/climate data with the advantage of pixel based analysis. In this study, LYMA $T_a$, $P_t$ and RH values of 27 meteorological stations in Eastern Thrace were analyzed and predicted using computed LYMA LST values corresponding to each station. The results show that in the absence of meteorological stations, LST, which has higher spatial resolution compared to meteorological models and satellites, can be used as an alternative to climatic data. Some of the major results are specific conclusions can be summarized as follows:

a) LYMA LST can be used to determine the LYMA $T_a$, RH and $P_t$;

b) LYMA LST is more predictive for LYMA $T_a$, then comes LYMA RH and then LYMA $P_t$. 
c) LST computation with atmospheric correction may not be preferred due to some less robust results depending on the geographic and weather conditions;

d) For the current study, both 5x5 and 3x3 filters seem to give similar results with a slight edge on the outcomes for the 5x5 filter.

Table 6 - Correlations between LYMA LST and LYMA T_a, P_t, and RH of corresponding stations.

| Station ID | T_a-LST r | T_a-LST r^2 | RMSE (°C) | P_t-LST r | P_t-LST r^2 | RMSE (mm) | RH-LST r | RH-LST r^2 | RMSE (%) |
|------------|-----------|-------------|-----------|-----------|-------------|-----------|-----------|-------------|-----------|
| 0          | 0.959     | 0.920       | 1.864     | -0.903    | 0.815       | 7.946     | -0.959    | 0.920       | 1.280     |
| 1          | 0.951     | 0.904       | 1.727     | -0.832    | 0.692       | 8.570     | -0.946    | 0.895       | 1.771     |
| 2          | 0.939     | 0.882       | 2.075     | -0.864    | 0.747       | 8.809     | -0.923    | 0.852       | 1.552     |
| 3          | 0.940     | 0.884       | 2.257     | -0.898    | 0.807       | 10.488    | -0.940    | 0.883       | 2.021     |
| 4          | 0.936     | 0.876       | 2.451     | -0.909    | 0.826       | 8.479     | -0.937    | 0.877       | 1.355     |
| 5          | 0.959     | 0.920       | 1.912     | -0.874    | 0.764       | 11.101    | -0.837    | 0.701       | 2.084     |
| 6          | 0.958     | 0.918       | 1.760     | -0.866    | 0.750       | 13.918    | -0.887    | 0.786       | 0.958     |
| 7          | 0.962     | 0.925       | 1.443     | -0.873    | 0.762       | 14.719    | -0.812    | 0.660       | 1.860     |
| 8          | 0.987     | 0.974       | 1.086     | -0.760    | 0.578       | 9.904     | -0.944    | 0.892       | 2.551     |
| 9          | 0.949     | 0.901       | 2.108     | -0.891    | 0.793       | 9.744     | -0.953    | 0.908       | 1.628     |
| 10         | 0.937     | 0.878       | 2.228     | -0.861    | 0.741       | 6.339     | -0.974    | 0.949       | 0.694     |
| 11         | 0.973     | 0.948       | 1.634     | -0.883    | 0.780       | 12.095    | -0.956    | 0.914       | 2.379     |
| 12         | 0.950     | 0.902       | 2.013     | -0.858    | 0.736       | 9.221     | -0.960    | 0.921       | 1.982     |
| 13         | 0.937     | 0.877       | 1.839     | -0.797    | 0.635       | 15.215    | -0.900    | 0.810       | 2.533     |
| 14         | 0.987     | 0.974       | 1.086     | -0.860    | 0.740       | 12.473    | -0.968    | 0.937       | 2.447     |
| 15         | 0.957     | 0.916       | 2.001     | -0.849    | 0.721       | 9.111     | -0.953    | 0.909       | 2.286     |
| 16         | 0.992     | 0.984       | 0.998     | -0.816    | 0.665       | 14.051    | -0.965    | 0.931       | 1.885     |
| 17         | 0.923     | 0.852       | 2.186     | -0.816    | 0.666       | 12.796    | -0.844    | 0.713       | 3.078     |
| 18         | 0.972     | 0.945       | 1.533     | -0.811    | 0.658       | 8.193     | -0.945    | 0.892       | 2.539     |
| 19         | 0.984     | 0.969       | 1.399     | -0.861    | 0.741       | 5.944     | -0.970    | 0.941       | 1.772     |
| 20         | 0.956     | 0.914       | 1.685     | -0.877    | 0.768       | 7.816     | -0.957    | 0.915       | 1.745     |
| 21         | 0.967     | 0.935       | 1.693     | -0.885    | 0.784       | 10.362    | -0.971    | 0.943       | 1.798     |
| 22         | 0.967     | 0.935       | 1.873     | -0.853    | 0.727       | 9.047     | -0.967    | 0.935       | 1.714     |
| 23         | 0.965     | 0.932       | 1.952     | -0.899    | 0.809       | 11.428    | -0.972    | 0.945       | 1.547     |
| 24         | 0.953     | 0.908       | 1.886     | -0.905    | 0.820       | 7.149     | -0.968    | 0.937       | 1.759     |
| 25         | 0.985     | 0.971       | 1.419     | -0.893    | 0.797       | 8.969     | -0.976    | 0.953       | 1.565     |
| 26         | 0.939     | 0.881       | 1.713     | -0.909    | 0.827       | 8.760     | -0.779    | 0.607       | 1.856     |
| Average    | 0.959     | 0.919       | 1.771     | -0.863    | 0.746       | 10.098    | -0.932    | 0.871       | 1.875     |

For future research, LYMA LST may be integrated with LYMA vegetation indices such as Normalized Difference Vegetation Index (NDVI) to compare climate data. Also, other parameters such as soil moisture may be included to the study. Finally, the different methods for LST retrieval such as split-window algorithm may be tested in the RSD processing system generated in this study.

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