International Journal of Modern Electronics and Communication Engineering (IJMECE) ISSN: 2321-2152
Volume No.-7, Issue No.-2, March, 2019

Estimation of Land Surface Temperature over Vegetated Region Using AVHRR Sensor Data and Validation with In-Situ Measurements

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Abstract: Surface temperature measurements over large spatial and temporal scales are necessary for many applications like urban land use/land cover, geo-/biophysical, climate, and environmental studies. Estimation of land surface temperature is difficult especially over vegetated and hard rock terrain and requires proper validation before use. Split window technique provides improved accuracy of estimation by accounting for atmospheric effects. NOAA AVHRR sensor provides split channel data and same has been used in this present study. Many Split window algorithms are available and in the present study the algorithms proposed by Becker, Sobrino and Ulivieri have been used. The area of interest to estimate LST is over Chittoor district, Andhra Pradesh, India, for the period March, 2017, using National Oceanic Atmospheric Administration (NOAA 19) – Advanced Very High Resolution Radiometer (AVHRR) thermal bands. AVHRR images of clear sky with nonhomogeneous land cover types have been used in this study. An attempt has been made to derive emissivity in the thermal channels using the Normalized Difference Vegetation Index (NDVI) along with the fractional vegetation cover at each pixel level. The results show that there exists a good correlation between the retrieved LSTs and the measured LSTs, when Ulivieri algorithm was used over the vegetated land cover type with an average RMSE value of 3.22.

Keywords: Advanced Very High Resolution Radiometer (AVHRR), Land Surface Temperature (LST), Land Surface Emissivity (LSE), Normalised Difference Vegetation Index (NDVI), Remote sensing.

I. INTRODUCTION

LST is one of the key parameters in assessing the energy exchange and matter between the atmosphere and the Earth's surface. Urbanization across the globe has significantly reshaped the landscape, which has an important impact on climatic changes at local and regional scales due to the changes in albedo and thermal exchanges [1]. The surface temperature can be measured using measuring instrument but not feasible over large areas. Accurate Land Use Land Cover (LULC) classification can be done by conducting ground surveys which are time consuming, burdensome and expensive. Remote sensing is the preferred alternative for land cover measurements and estimation of LST. Satellite remote sensing in the thermal infrared region of the electromagnetic spectrum provides an interesting alternative for the continuous global measurements of this parameter. Different algorithms have been developed to estimate Land Surface Temperature (LST), among which split window technique is the most popular. The present study focuses on the problem of estimating LST from AVHRR data. The AVHRR channels 4 and 5 (10.3–11.3 μm and 11.5–12.5 μm) are widely used for deriving surface temperature for daytime passes. Even though the spatial resolution of its High Resolution Picture Transmission (HRPT) is low i.e., 1.1 km x 1.1 km, AVHRR of NOAA has an advantage of high temporal resolution of about two images per day [2]. An advancement based on the dissimilar absorption in two adjacent infrared channels, called the 'split-window' technique, is used for determination of LST [3]. Ground emissivity has a notable effect on the accuracy of retrieved LST from remote sensing data. The atmospheric attenuation has effect on surface emissivity in the case of land [4]. Unlike sea surface, land surface thermal emission is highly variable because it depends on a large number of factors like pixel composition vegetation cover, soil background, and surface geometry, among others. Moreover, there is evidence of a spectral variation of surface emissivity for different land surface materials. The contrast of ground emissivity between channels 4 and 5 also has a remarkable impact on the accuracy of LST retrieval [5]. Several split window techniques (SWA) have been developed by considering many effects of the atmosphere and the surface emissions [6-13]. Among these, the techniques proposed by Becker [7], Sobrino [12], Ulivieri [13] are used for the study area and are developed in ERDAS IMAGINE 2016, using model maker.

II. STUDY AREA AND DATA

Chittoor district is a part of Rayalaseema area of Andhra Pradesh State, India as shown in Figure1. The district holds an area of 15,359 square kms (5,930 sq mi) and stretches between extreme south of the Andhra Pradesh state approximately between 12°37′ - 14°8′N and 78°3′ - 79°55′E (Lat/Long respectively). 30% of the whole land is enveloped by forests and composes of red loamy soil 57%, red sandy soil 34% and the rest 9% is covered by black clay, black loamy, black sandy and red clay soils.

Because of the higher altitude of the western parts of the district compared to the eastern parts, the temperature in the western parts like Punganur, Madanapalle, Horsley Hills are relatively lower than the eastern parts. The summer temperature rises up to 46 °C in the eastern parts whereas in the western parts it scales around 36° to 38 °C. In winter, temperatures of the western parts are relatively in low range around 12 °C to 14 °C and in eastern parts it is around 16 °C to 18 °C. It experiences an annual rainfall of 918.1 mm. The South West Monsoon and North East Monsoon are the key sources of rainfall for the region of interest [1].

Figure1. Geographic location of Chittoor region

A. Source of data for the study

The L-band High Resolution Picture Transmission/ Advanced High Resolution Picture Transmission (HRPT/AHRPT) receiver system has been set up at the Centre of Excellence (CoE) for "Atmospheric Remote Sensing and Advanced Signal Processing (ARS&ASP)" at Sri Venkateswara University, Tirupati, India (13.62°N, 79.41°E).

Table1. AVHRR Band Designations

Band	Wavelength (µm)	Resolution (m)	Swath Width (km)
Band 1 (Visible)	0.58 to 0.68	1100	3000
Band 2 (Near Infrared)	0.725 to 1.1	1100	3000
Band 3A (Near Infrared)	1.58 to 1.64	1100	3000
Band 3 (Infrared)	3.55 to 3.93	1100	3000
Band 4 (Thermal Infrared)	10.3 to 11.3	1100	3000
Band 5 (Thermal Infrared)	11.5 to 12.5	1100	3000

This provides continuous reception of data from NOAA/ METOP satellites. Satellite data over Chittoor region of day time pass have been used in this study. AVHRR High Resolution Picture Transmission (HRPT) images for three consecutive days in March, 2017 i.e., 25th, 26th and 25th were received and processed. The band designations of AVHRR sensor (multispectral) of NOAA satellite are given in Table 1.

III. METHODOLOGY

In the present study, LSTs were estimated from TIR bands of AVHRR radiometer (bands 4 & 5). The flow diagram of retrieving LSTs using NDVI and emissivity is shown in figure2.

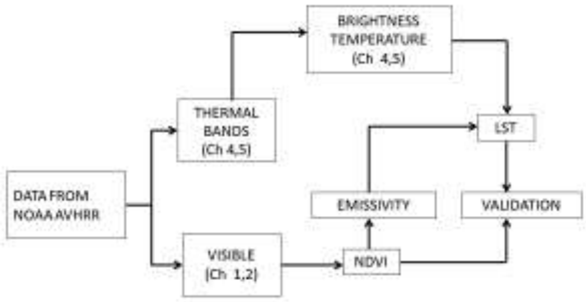


Figure2. Flow Diagram for retrieving LST from satellite data

The images received by the station established at S.V.University, Tirupati were collected. Using pixel data of channels 1 and 2, NDVI of each pixel is calculated using the following formula [1]

$$NDVI = \frac{NIR - RED}{NIR + RED} \qquad (1)$$

Where NIR is Near Infrared band and RED is visible band of AVHRR.

Normalized Difference Vegetation Index (NDVI) helps us to identify different land cover types of the study area. The range for NDVI is between -1.0 to +1.0. NDVI is calculated on per-pixel basis as the normalized difference between the red band (0.58 - 0.68µm) and near infrared band (0.725 - 1.1µm) of the images. Calculation of NDVI is also necessary to further estimate proportional vegetation (P_v) and emissivity (ε). Instead of using a theoretical knowledge about emissivity, Land Surface Emissivity (LSE) is derived using a simplified form of the NDVI threshold method [14]. The NDVI method first estimates the fractions of vegetation (P_v) and bare soil (1-P_v) in the field of view of the sensor [15]. The relation between NDVI and P_v is a square root relation as given in equation (2):

$$P_v = \left(\frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}}\right)^2 \qquad (2)$$

For 0.5 > NDVI > 0.2, Sobrino [11] utilises an empirical relationship between P_v and the mean LSE, and P_v and the spectral difference of LSE for AVHRR channels 4 and 5:

$$\varepsilon = \frac{(\varepsilon_4+\varepsilon_5)}{2} = \begin{cases} (0.971+0.018P_v), & 0.2 \le NDVI \le 0.5 \\ 0.989, & 0.5 < NDVI \\ 0.971, & NDVI < 0.2 \end{cases} \quad (3)$$

$$\Delta\varepsilon = (\varepsilon_4-\varepsilon_5) = \begin{cases} -0.006(1-P_v), & 0.2 \le NDVI \le 0.5 \\ 0, & 0.5 < NDVI \\ -0.006, & NDVI < 0.2 \end{cases} \quad (4)$$

Split Window Algorithm for deriving LST (Ts)

The general form of the SWA can be expressed as in the equation (5)

$$Ts = T4 + A(T4 - T5) + B \quad (5)$$

Where Ts represents the LST, T4 and T5 represent the brightness temperature for band 4 and 5 respectively, A and B are the coefficients determined by the impact of atmospheric conditions and other related factors on the thermal spectral radiance and its transmission in channels 4 and 5. The equations for coefficients A and B are given as follows:

$$A = (M - P)/2 \quad (6)$$
$$B = A_0 + T4(P - 1) \quad (7)$$

Where A, P and M were obtained by using a least squares fit method for 2180 situations given by Becker [7] as

$$A_0 = 1.274$$
$$P = 1 + 0.15616\left(\frac{1-\varepsilon}{\varepsilon}\right) - 0.482\left(\frac{\Delta\varepsilon}{\varepsilon^2}\right) \quad (8)$$
$$M = 6.26 + 3.98\left(\frac{1-\varepsilon}{\varepsilon}\right) + 38.33\left(\frac{\Delta\varepsilon}{\varepsilon^2}\right) \quad (9)$$

According to Sobrino algorithm [12]:

$$T = T4 + 1.06(T4 - T5) + 0.46(T4 - T5)^2 + 53(1-\varepsilon_4) - 53\Delta\varepsilon \quad (10)$$

According to Ulivieri algorithm [13]:

$$T = T4 + 1.8(T4 - T5) + 48(1-\varepsilon) - 75\Delta\varepsilon \quad (11)$$

IV. RESULTS

The estimated surface temperature and measured in-situ temperature at the data acquisition time were validated for the study area chosen. The selected stations have the vegetation type land cover and the results obtained are tabulated as shown in Table2. The average estimated surface temperature and standard error of measurement for each split window technique and for each station along with the average measured temperature for the three datasets selected are tabulated. Figure 3 shows the selected stations over the study area. The NDVI images derived from the processing of visible and near infrared of the satellite images are shown in Figure 4 for the three days. Figure 5 shows the LST images obtained by processing thermal bands of AVHRR for each technique i.e., *Becker*, *Sobrino* and *Ulivieri*. Figure 6 shows the RMSE plots for each technique for the stations considered in study area.

Table2. Average Estimated Temperature Vs. Average Measured In-Situ Temperature

S. No.	STATION	AWS Data (°C)	ESTIMATED SURFACE TEMPERATURE T_s (°C)					
			BECKER & LI		SOBRINO		ULIVIERI	
		$AvgT_a$	$AvgT_s$	RMSE	$AvgT_s$	RMSE	$AvgT_s$	RMSE
1	Renigunta	39.2	44.68	5.49	46.09	6.98	41.57	2.44
2	Kothapallimitta	37.55	42.85	5.30	42.5	5.22	40.38	3.11
3	Nadavaluru	39.37	43.96	5.04	45.66	6.47	41.9	2.71
4	Somala	35.88	42.41	6.56	42.32	6.62	38.81	3.51
5	Sindurajapuram	39.53	44.02	4.67	44.44	5.46	41.68	2.90
6	Bonupalle	37.17	41.69	4.54	41.67	4.78	39.92	3.01
7	K V B Puram	39.18	42.76	3.69	45.47	6.46	39.4	3.36
8	Gangudupalle	38.15	42.3	4.43	43.84	5.94	40.79	2.83
9	Cheelapalle	37.32	43.29	6.14	45	7.84	41.65	4.37
10	BNRPeta	38.2	42.41	4.23	43.34	5.20	41.4	3.38
11	Kattakindapalle	36.77	42.44	5.80	43.03	6.33	40.42	3.72
12	shivaramapuram	37.13	42.51	5.55	41.82	5.33	39.78	2.85
13	Suratpalle	36.22	39.95	4.44	39.61	3.86	38	3.22
14	Karani	35.68	39.41	4.15	39.28	3.62	38.88	3.69

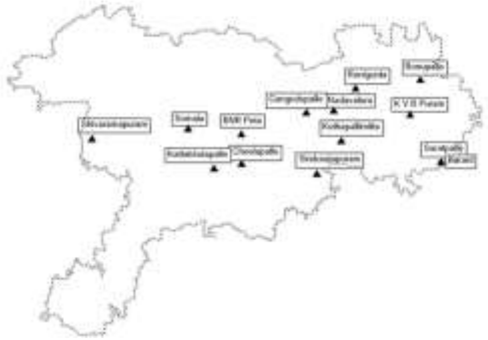
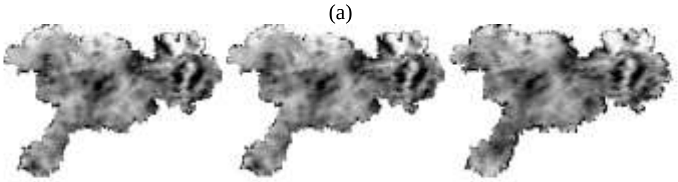


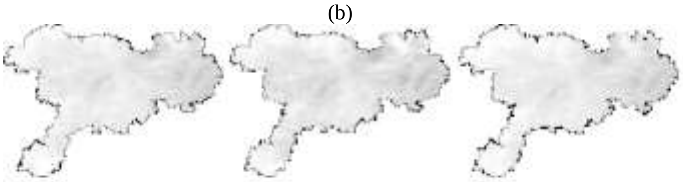
Figure3. District map with the selected stations highlighted

Figure4. NDVI images for 25.03.2017, 26.03.2017 & 27.03.2017

(a)



(b)



(c)

Figure5. LST images for 25.03.2017, 26.03.2017 & 27.03.2017

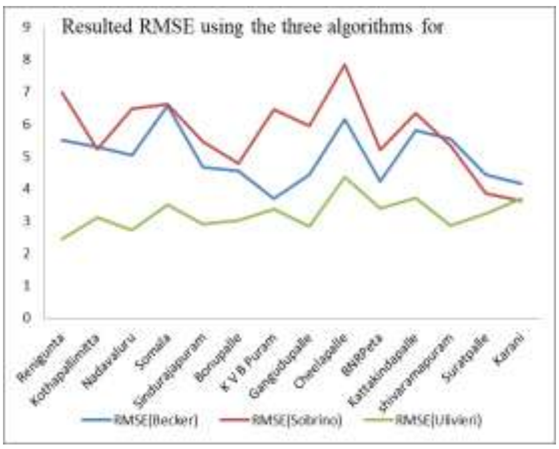


Figure6. RMSE plot for different stations

V. Conclusions

Three split window algorithms have been applied to find an optimal algorithm to estimate LSTs from thermal bands of AVHRR data in the selected study areas of the Chittoor region. Cmparisons between the three split window algorithms applied over vegetated land cover type were carried out to examine their relative accuracy in the selected land cover type. The results of the work done could be summarized as follow:

- The applicability of split window technique to estimate Ts has been investigated by comparing the surface temperatures estimated by three of the best split window techniques against actual measured AWS temperature. The averages of AWS data and the estimated LSTs are tabulated in Table 2. The results show that the RMSE value obtained using *Ulivieri* algorithm is less compared to other two techiques, *Becker* and *Sobrino*. The average RMSE value of LST over different sites, when compared to AWS data for *Ulivieri* technique is 3.22 and whereas RMSE values for other two algorithms are 5.00 and 5.72 respectively. The comparison was made with air temperature of AWS station, which is not same and can sometimes result in big errors since the resolution of AVHRR 1.1km for the thermal and optical bands. The LST was calculated and taken for the pixel in which the AWS is located. The differences may also be due to some weather conditions and sensor characteristics of the AWS. And the other thing that has to be taken into consideration is the location of the thermal sensor in AWS which is at an altitude of 2 meters.
- Further, the work can be extended with the time series data to know the changing temperature pattern of the region of interest.

Acknowledgement

The authors are extremely grateful to the Coordinator, Centre of Excellence on "Atmospheric Remote Sensing and Advanced Signal Processing", at Department of ECE, S V University College of Engineering, Tirupati, Andhra Pradesh, India, for providing necessary data and software resources to carry out the present work. The Andhra Pradesh State Development Planning Society (APSDPS) is acknowledged in this research for providing AWS data to perform validation of the estimated results.

Conflicts of Interest

The authors declare no conflict of interests.

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